Volume 18, Number 1

March 2022

IJCB INTERNATIONAL JOURNAL OF CENTRAL BANKING
Volume 18, Number 1 March 2022

IJCB
INTERNATIONAL JOURNAL OF CENTRAL BANKING

IJCB International Journal of Central Banking

Volume 18, Number 1 March 2022

The contents of this journal, together with additional materials provided by article authors, are available without charge at ***www.ijcb.org***.

The *International Journal of Central Banking* is published quarterly (ISSN: 1815-4654). Online access to the publication is available free of charge at **www.ijcb.org**. Changes to hard copy subscriptions and orders should be placed by e-mail at editor@ijcb.org.

Renewals, claims, address changes, and requests for permission to reprint material from this journal should be addressed to:

International Journal of Central Banking
HS08.20
European Central Bank
Sonnemannstr. 22
D-60640 Frankfurt am Main
Germany

Phone: +4969134495894
E-mail: editor@ijcb.org

ISSN: 1815-4654

International Journal of Central Banking

Introduction

This issue of the *International Journal of Central Banking* includes two of the papers presented at the conference entitled "The Macroeconomic Consequences of COVID-19" hosted by the European Central Bank on August 9–10, 2021. The conference was co-organized with Bank of Korea and the European Central Bank. The two papers, chosen using the same rigorous standards applied to all *International Journal of Central Banking* content, are "Does Policy Communication during COVID Work?" by Olivier Coibion, Yuriy Gorodnichenko, and Michael Weber; and "Monetary Policy and COVID-19" by Michał Brzoza-Brzezina, Marcin Kolasa, and Krzysztof Makarski. The program committee for the conference was Klaus Adam, Boragan Aruoba, Òscar Jordà, Sharon Kozicki, Keith Kuester, and Luc Laeven.

Does Policy Communication during COVID Work?*

Olivier Coibion,[a,b] Yuriy Gorodnichenko,[b,c] and Michael Weber[b,d]
[a]University of Texas, Austin
[b]NBER
[c]University of California, Berkeley
[d]University of Chicago Booth School of Business

Using a large-scale survey of U.S. households during the COVID-19 pandemic, we study how new information about fiscal and monetary policy responses to the crisis affects households' expectations. We provide random subsets of participants in the Nielsen Homescan panel with different combinations of information about the severity of the pandemic, recent actions by the Federal Reserve, stimulus measures, as well as recommendations from health officials. This experiment allows us to assess to what extent these policy announcements alter the beliefs and spending plans of households. In short, they do not, contrary to the powerful effects they have in standard macroeconomic models.

JEL Codes: E31, C83, D84, J26.

The single biggest problem in communication is the illusion that it has taken place.

–*George Bernard Shaw*

[*For monetary policy to be most effective*] *not only do expectations about policy matter, but, at least under current conditions, very little else matters.*

–*Woodford (2005)*

*We thank the National Science Foundation for financial support (grant number SES-1919307) in conducting the surveys. We also thank Shannon Hazlett and Victoria Stevens at Nielsen for their assistance with the collection of the PanelViews Survey, as well as Carola Binder, Luc Laeven, and an anonymous referee for helpful comments. The randomized control trial is registered at the AER RCT Registry (#AEARCTR-0005989).

1. Introduction

Monetary and fiscal policies affect the economy (Romer and Romer 2004, 2010), but how they operate remains a point of contention. A common thread across many macroeconomic models is the role of expectations: policies have powerful effects in modern mainstream models in large part because firms and households incorporate these announcements into their decision plans. In real business cycle models, for example, an announcement of higher government spending should make households feel poorer (since they will have to pay for this spending via higher taxes now or in the future), which induces them to work more. Forward guidance on the part of monetary policymakers is predicted to have large effects in New Keynesian models because the promise of future lower interest rates by the central bank should induce households to anticipate higher inflation in the future, which in turn should lead them to consume more today before those price increases materialize.

How powerful are these mechanisms in practice? Recent research should give one pause: there is a growing body of evidence documenting that, in advanced economies, inattention to macroeconomic policy and the broader economic environment is pervasive among households and firms. Announcements by monetary and fiscal policymakers are rarely found to have large effects on the expectations of economic agents other than those participating directly in financial markets, suggesting that these expectational forces may in fact be quite weak. Still, one might expect a strengthening of these forces in a crisis, as a worried population turns its attention to its leaders for guidance and support.

Using a large-scale survey of U.S. households during the COVID-19 pandemic, we study how new information about policy responses affects the expectations and decisions of respondents. Specifically, we provide random subsets of participants with different combinations of information about the severity of the pandemic, recent actions by the Federal Reserve, stimulus measures implemented by Congress, as well as recommendations from the U.S. Center for Disease Control (CDC). We then characterize how their economic expectations and spending plans respond to these information treatments. This allows us to assess to what extent these policy announcements alter the beliefs and plans of economic agents.

By and large, we find very little effect of these information treatments on the economic expectations of agents for income, mortgage rates, inflation, or the unemployment rate, nor do we find an effect on their planned decisions, contrary to the powerful effects they have in standard macroeconomic models. Why might agents' economic beliefs not respond to this information? One possible explanation is that they were already aware of the information provided in the treatments. For example, the policy announcements that we describe were widely covered in the press. Health pronouncements by government officials were also frequent headliners in national media. If the effect of these announcements were already reflected in household expectations, our treatments would not be providing any new information to households and should therefore have no effects on expectations. However, we view this possibility as unlikely to be driving our results. For example, households' prior beliefs about the transmission rate of COVID-19 or its recovery rate were wildly misinformed prior to the information treatments, even though these rates were widely discussed in the media. Furthermore, previous work has documented how uninformed households tend to be about most monetary and fiscal policies and how even large policy announcements do not make their way into households' aggregate expectations, even in the midst of a crisis (e.g., Coibion, Gorodnichenko et al. 2020). Furthermore, Binder (2020) documents that even after the historic policy actions of the Federal Reserve in response to the COVID-19 crisis, only a third of U.S. households had heard about these policy actions.

A second possible explanation for finding no effect of information treatments is if households are skeptical of the information that we provide. Again, we view this as very unlikely because other information treatments in identical settings have previously been found to lead to dramatic revisions in households' views about the economy (e.g., Coibion, Gorodnichenko, and Weber 2019). A third possible explanation rests on the idea that, because of cognitive constraints, many households might not directly understand the implications of complex policies for their optimal savings and consumption decisions (e.g., D'Acunto, Hoang, and Weber 2021, D'Acunto, Hoang et al. 2021). The fourth, and in our view most likely, explanation is that households do not believe that the policy responses described in the treatments are effective: i.e., the multipliers they associate with the described policy responses are close to zero. These zero multipliers could be interpreted in one of two ways. According to the first one, households literally believe that changes in monetary or fiscal policy have little direct impact on macroeconomic outcomes. The second interpretation reflects the endogeneity of the policy decisions: large expansionary policy actions are taken only in times when economic conditions are particularly weak. Policy announcements may then have little effect on overall economic expectations, as they convey negative information about the state of economy along with positive information about policy actions, with the two washing out on average.

Our paper builds on a recent but growing literature in macroeconomics that relies on surveys to measure expectations and randomized information treatments to establish causality (e.g., Cavallo, Cruces, and Perez-Truglia 2017, Coibion, Gorodnichenko, and Kumar 2018, Armona, Fuster, and Zafar 2019, D'Acunto et al. 2020, D'Acunto, Fuster, and Weber 2021, D'Acunto, Hoang, and Weber 2021). We depart from previous work along several dimensions. First, we use a large-scale survey of U.S. households participating in the Nielsen Homescan panel, providing us with a sample size that is an order of magnitude larger than in commonly available surveys. Second, our survey was run in April 2020 in the midst of the COVID epidemic, so we are able to study the dramatic policy actions taken specifically in response to the outbreak. In addition, we are able to provide new insight about how informed households were about both the deadliness of the disease and how it spreads across the population. There has been a surge of research on the coronavirus in recent months, much of it relying on surveys. We build on this growing body of work by utilizing randomized control trials (RCTs) to study the effects of economic policy responses to the crisis. Third, we combine treatments about the severity of the disease with treatments not only about economic policy responses (e.g., fiscal and monetary) but also about health policies (recommendations from the CDC). This allows us to speak about the relative benefits of very different types of policy responses within a common framework.

Previous work has documented extensively how inattentive households (and firms) tend to be to macroeconomic conditions (Bachmann, Berg, and Sims 2015, Coibion, Gorodnichenko, and

Kumar 2018, Coibion et al. 2019, D'Acunto et al. 2019). We find the same qualitative patterns hold during the COVID crisis but also document that this lack of understanding extends to information about the coronavirus. For example, when we ask households what they think the recovery rate is once infected with COVID, they report an average answer of 73 percent, far lower than the 97 percent reported by the World Health Organization (WHO). Similarly, when we ask them how many people tend to be infected by someone carrying the COVID virus, their average answer is 21, far higher than the actual rate of around 2 estimated by the WHO. This suggests that information treatments that provide factual information about transmission and recovery rates could potentially have important effects on households' expectations about the economy.

Despite this, we find very small effects of providing information about the deadliness and ease of spread of the disease on households' expectations. When respondents are treated with information that, on average, the disease is harder to spread and less deadly than they had originally thought, their views about future inflation, mortgage rates, and unemployment are effectively unchanged. They reduce their reported expected future income on average, but the change is economically insignificant. Their perceptions about whether now is a good or bad time to buy durables are also effectively unchanged. The one exception is for unemployed workers who are asked about the likelihood of finding a job: those who are treated with information about the disease raise their likelihood of finding a job by about 20 percentage points. These results suggest that the large changes in expectations during the COVID-19 pandemic for income, the stock market, or mortgage rates are less likely driven by direct concerns about the virus but more likely a response to the lockdowns imposed by local authorities in line with findings in Coibion, Gorodnichenko, and Weber (2020).

Information treatments about fiscal, monetary, or health policies similarly do very little to the expectations of households, both about the aggregate economy and about their own income. And when they do, those effects are not necessarily positive. For example, among the unemployed who become more optimistic about their future job prospects when they are told that COVID-19 spreads less easily and is less deadly than they thought, providing additional information about the responses of policymakers fully offsets the effect of the information about the disease. This is again consistent with the presence of an information effect to policies: finding out that fiscal, monetary, or health policymakers are implementing large policy changes makes the unemployed less optimistic about their job prospects, but only when done in conjunction with information about the disease. Information treatments that are only about policy changes have effectively no effect on most agents' macroeconomic or individual expectations. These results are consistent with recent findings documenting an information effect of monetary policy which suggest that large policy moves might reveal information about the state of the economy which is called Delphic in the context of forward guidance (see, e.g., Campbell et al. 2012).

By studying the effect of policy actions on households' macroeconomic expectations through RCTs, our paper is closest to Andre et al. (2019). They present specific scenarios of both fiscal and monetary shocks to households (as well as experts) to assess how they believe these shocks will affect the economy. They find that households' views about fiscal shocks are similar to those of experts, but their perceptions of how monetary shocks affect the economy differ significantly from those in standard models or those perceived by experts. One important difference is that Andre et al. (2019) present respondents with hypothetical exogenous shocks to either fiscal or monetary policy, whereas we present households with information about clearly endogenous policy responses. Our results therefore speak directly to the effects of *systematic* policy changes, whereas theirs are focused on exogenous policy. Our findings suggest that these systematic policy responses have little effect on households' expectations, either because they believe they are ineffective or because policy responses induce an information effect (in which households interpret the sheer fact of a policy response as indicative of a weaker economy) that effectively offsets the effect of the policy change.

Our work is also closely related to that of Binder (2020) and Fetzer et al. (2020), who assess how randomized provision of COVID-19 health facts influences concerns (about personal financial situation and about aggregate economy) of households participating in online surveys.[1] Apart from the fact that we are using a survey that is an order of magnitude larger in size (and hence more precise estimates of treatment effects), we also study how the provision of health facts and/or policy responses shapes expectations. Like these studies, however, it must be emphasized that our survey was run at the beginning of a pandemic when uncertainty was widespread. This represents a unique setting, and effects of information treatments during this time may not necessarily carry over to other settings. While we view the fact that the survey was run during the height of the crisis as a plus since crises are rare, the external validity of the results may be more limited than RCTs during more normal conditions.

Our research also relates to a broader literature on the effect of monetary policy on household expectations. That literature has documented that monetary policy decisions and announcements have little to no effect on household inflation expectations (e.g., Lamla and Vinogradov 2019, Coibion, Gorodnichenko et al. 2020). This result is generally interpreted as indicating that households are unaware of the policy actions. Our results suggest an additional possible mechanism underlying these results: even when households are made aware of these policy decisions, they do not view them as having meaningful effects on the aggregate economy. Hence, it is not only important to reach households with communication but also to design and implement policies that are easy and simple to grasp for non-expert households and to explain the implications of policies for optimal consumption, savings, and investment decisions (D'Acunto, Hoang, and Weber 2021).

2. Survey Description

In this section, we describe the implementation of the survey as well as the information treatments. We build on our earlier work (Coibion, Gorodnichenko, and Weber 2019; Coibion, Georgarakos et al. 2020; D'Acunto, Malmendier, and Weber 2020; D'Acunto,

[1]Binder (2020) also uses a difference-in-difference approach to study how informing households about the Federal Reserve's policy rate cut changes expectations.

Malmendier et al. 2021) using the Nielsen Homescan panel to study expectations and spending decisions.

2.1 The Survey

Our survey was run in April 2020 on the Nielsen Homescan panel of households. This panel consists of 80,000–90,000 households who track their spending daily for A.C. Nielsen. Following Coibion, Gorodnichenko, and Weber (2019) and Coibion, Georgarakos et al. (2020), we ran a survey on these households that included various information treatments that we provided in a randomized fashion. The survey consisted of an initial set of questions designed to measure the prior beliefs and plans of households, followed by a randomized information treatment, and concluding with a final set of questions meant to assess how/whether treatments affected the expectations and plans of participants. A total of 13,771 individuals responded to the survey, yielding a response rate of 27 percent. The response rate compares favorably to the average response rates of surveys on Qualtrics, which is the most commonly used survey platform for online surveys that estimates a response rate between 5 percent and 10 percent. Survey questions are provided in the appendix.

Nielsen attempts to balance the panel on nine dimensions: household size, income, age of household head, education of female household head, education of male household head, presence of children, race/ethnicity, whether or not the household is Hispanic, and occupation of the household head. Panelists are recruited online, but the panel is balanced using Nielsen's traditional mailing methodology. Nielsen checks the sample characteristics on a weekly basis and performs adjustments when necessary. Nielsen provides sampling weights to correct for possible imbalances in the composition of respondents in our survey. All of our reported results use sampling weights.

Nielsen provides households with various incentives to guarantee the accuracy and completeness of the information households report. They organize monthly prize drawings, provide points for each instance of data submission, and engage in ongoing communication with households. Panelists can use points to purchase gifts from a Nielsen-specific award catalog. Nielsen structures the incentives to not bias the shopping behavior of their panelists. The Kilts-Nielsen Consumer Panel (KNCP) has a retention rate of more than 80 percent at the annual frequency. Nielsen validates the reported consumer spending with the scanner data of retailers on a quarterly frequency to ensure high data quality. The KNCP filters households that do not report a minimum amount of spending over the previous 12 months. Information on scanned consumer spending is available only with a pronounced lag, however, so we are not yet able to combine information from our survey responses with underlying spending decisions on the part of households.

Table 1 reports moments of initial beliefs and expectations reported by households. We present raw moments as well as "robust" moments controlling for outliers using Huber (1964) robust methods, and we focus on the latter in our discussions. On average, households in April 2020 perceived an inflation rate of 2.6 percent and expected a lower inflation rate of 1.7 percent over the next 12 months, significantly lower than in other comparable survey waves of Nielsen panelists (e.g., Coibion, Gorodnichenko, and Weber 2019, Coibion, Georgarakos et al. 2020). Inflation expectations and perceptions exhibit significant cross-sectional dispersion, with a standard deviation of close to 3 percent. This dispersion can also be seen in Figure 1, which plots the distribution of answers as well as the current value of the variable at the time of the survey (vertical line). Unlike in previous waves, households believed that the unemployment rate was nearly 10 percent in April and expected an even higher rate of unemployment 12 months later (nearly 11 percent). Disagreement about both current and future unemployment was also pervasive, as illustrated in panels C and D of Figure 1. Table 1 also reports households' perceptions of the current mortgage interest rate as well as their expectations for this interest rate at the end of 2020, the end of 2021, and over the longer horizon of three to five years. The average belief about the current mortgage rate was 3.6 percent, close to the average value of 3.3 percent on March 26, 2020, with households anticipating a very gradual increase in mortgage rates over the next three to five years.[2] As illustrated in panels E and F of Figure 1,

[2]The survey is conducted over mortgage lenders originating loans in the United States. See FRED, Federal Reserve Bank of St. Louis; https://fred.stlouisfed.org/series/MORTGAGE30US.

Table 1. Descriptive Statistics

	Huber-Robust Moments		Raw Moments		
	Mean (1)	St. Dev. (2)	Mean (3)	Median (4)	St. Dev. (5)
Pre-treatment Data					
Perceived Inflation, Previous 12 Months	2.61	2.47	4.67	3.00	10.00
Expected Inflation, Implied Mean, 12-Month Ahead	1.66	3.26	1.70	1.29	5.81
Perceived Unemployment Rate, Current	9.79	6.77	12.66	10.00	9.58
Expected Unemployment Rate, 12-Month Ahead	10.64	6.53	13.10	10.00	9.04
Expected Unemployment Rate, in 3–5 Years	6.08	3.54	9.50	6.00	7.93
Expected Household Income Growth, 12-Month Ahead	—	—	−2.36	0.00	14.39
Perceived and Expected Mortgage Rate for a "Person Like You"					
Current	3.57	1.08	5.46	3.80	5.64
End of 2020	3.55	1.38	5.79	4.00	6.11
End of 2021	4.09	1.42	6.24	4.00	6.00
Next 5–10 Years	4.61	1.56	7.25	5.00	7.98
Post-treatment Data					
Expected Inflation, Point Prediction, 12-Month Ahead	3.93	3.68	6.64	4.00	9.57
Expected Unemployment Rate, End of 2020	10.61	6.54	13.20	10.00	9.18
Expected Unemployment Rate, Next 3–5 Years	5.32	2.88	8.93	5.00	7.93
Expected Household Income Growth, 12-Month Ahead	0.52	1.71	1.04	0.00	17.77
Perceived and Expected Mortgage Rate for a "Person with Excellent Credit"					
Current	3.63	1.21	5.62	4.00	5.97
End of 2020	3.72	1.47	5.96	4.00	6.16
End of 2021	4.16	1.41	6.32	4.00	6.10
Next 5–10 Years	4.57	1.53	6.57	5.00	5.93

Note: Pre-treatment expected inflation (12 months ahead) is computed as mean implied from the reported probability distribution over a range of bins. All other measures of inflation are reported as point predictions. Perceived and expected mortgage rates are elicited for "a person like you" at the pre-treatment stage and for "someone with excellent credit" at the post-treatment stage. Moments in columns 1 and 2 are computed using the Huber-robust method. Because many households report zero changes in household income, the Huber method to compute moments robust to outliers does not converge and hence robust moments are not available for pre-treatment expectations for household income growth.

Figure 1. Perceptions and Expectations

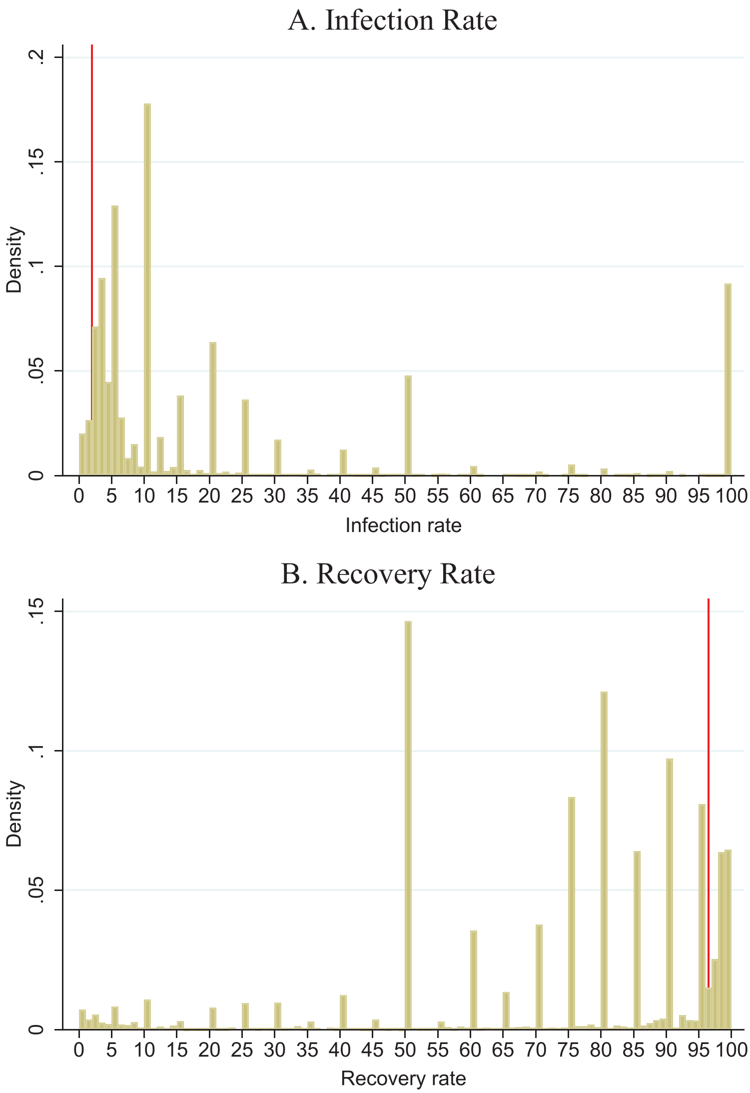
Note: Each panel plots the distribution of pre-treatment beliefs in the Nielsen household panel. The red, vertical line shows the current value of the corresponding variable at the time of the survey (for figures in color, see online version at http://www.ijcb.org). Panels A, C, and E report perceptions of current values. Panels B, D, and F report one-year-ahead forecasts.

however, there is significant disagreement across households about the path of future interest rates.

Respondents were also asked questions about COVID-19. First, we asked them about the infection rate, i.e., how many uninfected people might be expected to be infected by one person carrying the virus. As panel A of Figure 2 documents, households reported a wide range of answers, with many answering 100 or more. Very few gave answers close to the WHO's estimate of an infection rate of 2, suggesting that most households significantly over-estimated how contagious the virus actually is. Second, they were asked about how lethal the virus is. Specifically, we asked them how likely a person was to survive after having been infected with the virus, i.e., the recovery rate. We plot responses to this question in panel B of Figure 2. Again, the range of answers provided by households is enormous, with a recovery rate of 50 percent being the most commonly provided answer, nowhere near the answer of 96–97 percent provided by the WHO. We conclude that, consistent with Binder (2020) and Fetzer et al. (2020), households were very uninformed about the actual contagiousness and danger of the disease, with most households being far more pessimistic about the disease than health authorities.

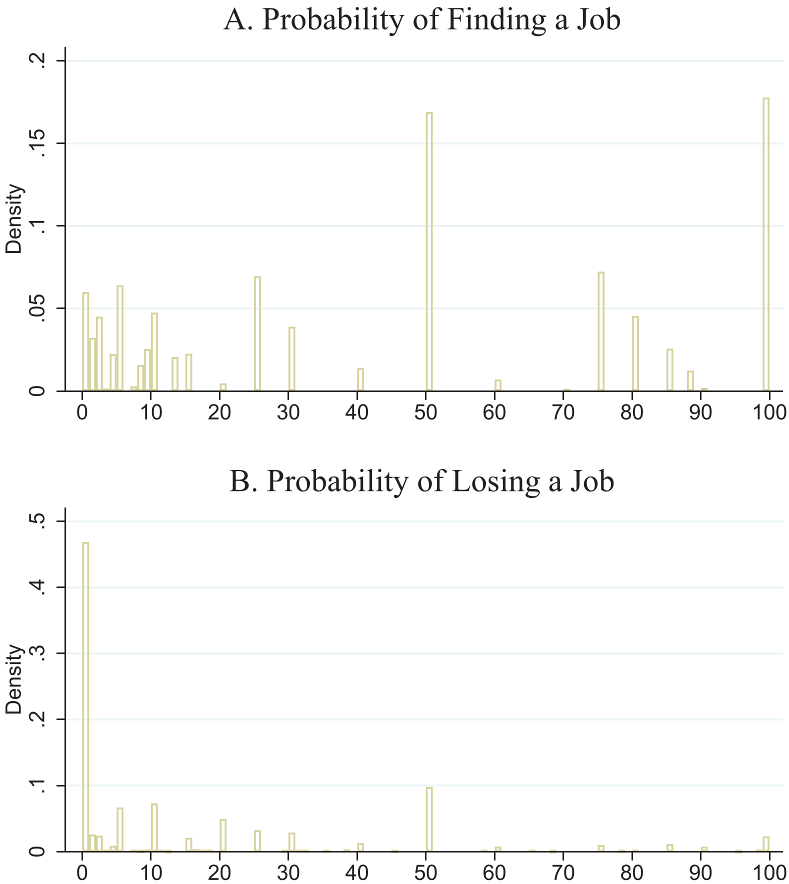
Finally, respondents were also asked about expectations about their own economic situation. For example, we asked them to report how they expected their income to change over the next 12 months. As reported in Table 1, the raw average was –2.4 percent, again masking significant variation (cross-sectional standard deviation of 14 percentage points). In addition, we asked respondents to tell us whether they were currently employed. Those reporting being employed were then asked about the probability of losing their jobs over the next 12 months. Panel B of Figure 3 plots the resulting distribution of answers. Most respondents report a probability very close to or equal to 0 percent, indicating limited concerns about losing their jobs. For those reporting that they were not currently employed but are looking for a job (approximately 7 percent of respondents), we asked them about the probability of finding a job over the next 12 months. As illustrated in panel A of Figure 3, answers were extremely dispersed. While some report probabilities of finding a job close to 100 percent, almost as many report a probability of just 50 percent and 32 percent report a probability of 10 percent or less.

Figure 2. Distribution of Beliefs about How Contagious and Fatal the COVID-19 Virus Is



Note: Panel A: Infection rate is measured as the response to the following question: "Think of a person who has the coronavirus. How many non-infected people do you think will catch the virus from this person?" The response is winsorized at 100. Panel B: The recovery rate is measured as the response to the following question: "If a person contracts coronavirus, what do you think is the probability that this person recovers from the virus? Please enter a number between 0 (Do not recover) and 100 (Recover for sure)." In each panel, the red, vertical line shows the estimates provided by the World Health Organization.

Figure 3. Subjective Probabilities for Labor Market Transitions



Note: The histograms plot distribution of perceived probabilities of finding a job (panel A) and losing a job (panel B). Both panels report data for the control group only. Panel A is only for people who are unemployed (don't have a job and look for a job). Panel B is only for people who have a job.

2.2 Treatments

After being asked this initial set of questions, respondents were then randomly assigned to one of multiple treatments groups. The first group is the control group, which does not get any information.

Table 2. Summary of Treatments

Treatment	Health Information Is Provided (Basic COVID-19 Facts about Recovery and Contagion Rates)	Policy Response Is Provided
T1 (Control)	No	No
T2	No	Fed Actions
T3	No	Congress Actions
T4	No	Fed and Congress Actions
T5	No	Health Officials (CDC Recommendations and the Prevalence of Shelter-in-Place Orders)
T6	Yes	No
T7	Yes	Fed Actions
T8	Yes	Congress Actions
T9	Yes	Fed and Congress Actions
T10	Yes	Health Officials (CDC Recommendations and the Prevalence of Shelter-in-Place Orders)

However, they still receive the same set of follow-up questions which allow us to measure any change in their expectations for comparison to treatment groups. Even though they are not provided with information, we may still observe changes in expectations because the wording of questions pre- and post-treatment is generally different, a strategy we employ to avoid respondents leaving the survey if they are being asked the same questions twice. For example, inflation expectations are initially measured using a distributional question, while posterior beliefs are measured by respondents being asked to provide a point estimate. Because the wording of questions can lead to some differences in answers, having the control group answering both sets of questions allows us to control for any effect that different wording may induce.

Respondents not assigned to the control group were randomly placed in one of nine groups, as summarized in Table 2. These nine groups differ first in terms of whether they received information about the COVID-19 virus, and second in terms of whether they were provided with additional information about fiscal, monetary, or health policies of the government. With respect to the information about the virus, approximately half of non-control group participants received the information about the virus (treatment groups 6–10), while the other half did not (treatment groups 2–5). The specific wording used in providing the WHO information about the virus to treatment groups 6–10 was as follows:

> According to official estimates of the World Health Organization for these rates: The recovery rate from the coronavirus is approximately 96–97 percent (that is, there is 96–97 in 100 chance to recover). Approximately 2 non-infected people will catch the coronavirus from a person who has the coronavirus.

In addition to the possibility of being treated with information about the severity of the COVID epidemic, households could also randomly be treated with information about the fiscal policy response (treatment groups T3 and T8), the monetary policy response (treatment groups T2 and T7), both (treatment groups T4 and T9), neither (control group T1 and treatment group T6), or the recommendations from health officials (treatment groups T5 and T10). For each type of policy treatment, we therefore have two treatment groups: one that also received the information treatment vis-à-vis the severity of the disease and one that only received the policy treatment. The objective of this exercise is to measure the effectiveness of policy communication when background information is also provided. This feature of our survey is a key innovation relative to previous research that studies the effects of information provision on expectations such as Coibion, Georgarakos et al. (2020) that treat households with forward guidance by the Federal Reserve. Treatments about the path of future interest rates as in Coibion, Georgarakos et al. (2020) allow clean identification of treatments on revisions of expectations but possibly do not provide all necessary information to policymakers that are interested in the response of households to *endogenous* policy actions. In the context of forward guidance, for example, one might want to study the effect of providing information on future interest rates with conditional statements typically used by the Federal Reserve such as “until the unemployment rate falls below x%.” We build on this work by providing real-world information treatments that explicitly identify endogenous policy actions.

The specific, truthful policy treatments that we consider are as follows. The monetary policy treatment is given by the following quote:

> In response to the COVID-19 crisis, the Federal Reserve reduced short-term interest rates to zero and implemented additional measures similar to what it did during the last recession.

The fiscal policy treatment is given by the following:

> In response to the COVID-19 crisis, the Congress approved a $2 trillion package to stimulate the economy, including one-time $1,200 checks per person (plus another $500 per child) to persons with annual income less than $75,000. Couples who filed jointly and made less than $150,000 will get a one-time $2,400 check (plus another $500 per child).

The joint monetary and fiscal treatment is as follows:

> In response to the COVID-19 crisis, the Federal Reserve reduced short-term interest rates to zero and implemented additional measures similar to what it did during the last recession. In addition, the Congress approved a $2 trillion package to stimulate the economy, including one-time $1,200 checks per person (plus another $500 per child) to persons with annual income less than $75,000. Couples who filed jointly and made less than $150,000 will get a one-time $2,400 check (plus another $500 per child).

The health recommendation treatment is as follows:

> The U.S. government health officials encourage social distancing, avoiding discretionary travel, and working remotely. Three in four Americans are in areas with local governments declaring "shelter in place" (lockdown).

If provided, these information bits about policy responses appear immediately after the WHO health facts. Note that both the fiscal and monetary treatments (as well as the joint monetary–fiscal treatments) explicitly tie the policy response to the COVID-19 crisis, indicating that these are *endogenous* policy responses unlike the *exogenous* shocks proposed to households in Andre et al. (2019). Consistent with random assignment of treatments, we find (Table A.1 in the online appendix at http://www.ijcb.org) that treatment status is not predicted by personal/household characteristics.

3. Econometric Framework

To measure the effect of policy communications on households' beliefs and plans, we use the following specification as a baseline:

$$E_i^{post}(X) - E_i^{prior}(X) = \sum_{s=1}^{S} \beta_s \times Treatment_{s,i} + error, \qquad (1)$$

where i indexes respondents, X is an outcome variable, $E_i^{post}(\cdot)$ and $E_i^{prior}(\cdot)$ are post-treatment ("posterior") and pre-treatment ("prior") beliefs of respondent i about variable X and $Treatment_{s,i}$ is an indicator variable equal to one if respondent i received treatment s and zero otherwise. The β_s coefficients provide an estimate of the average effect of each treatment on the revision in beliefs. Although one may expect that β for the control group is equal to zero, differences in the wording of the pre- and post-treatment questions, mean reversion in the responses, and the like can generate non-zero belief revision for the control group. We will therefore report $\hat{\beta}$ for a treatment group relative to $\hat{\beta}$ for the control group.

While specification (1) provides a useful summary of information treatments on the beliefs, it may give an incomplete picture of how treatments influence beliefs if the provided signals happen to be in the middle of the distribution for prior beliefs. For example, if households believe on average that inflation will be 2 percent, treating households with a 2 percent inflation projection prepared by professional forecasters will not move the average belief in the treatment group, but it should make the posterior distribution more concentrated on 2 percent by moving beliefs of those who initially predicted inflation other than 2 percent closer to 2 percent after the treatment. While our treatments do not have a numeric forecast and so it is hard to assess whether provided information is in the middle or tail of prior distributions, we can nonetheless utilize an alternative specification to measure this more subtle adjustment of beliefs:

$$E_i^{post}(X) = \sum_{s=1}^{S} \beta_s \times Treatment_{s,i} + \sum_{s=1}^{S} \gamma_s \times Treatment_{s,i} \times E_i^{prior}(X) + error. \quad (2)$$

In this specification, βs and γs measure "level" and "slope" effects of treatments, respectively. If a signal happens to be above (below) the average pre-treatment belief, β should be positive (negative). As discussed in e.g., Coibion, Georgarakos et al. (2020), estimated slopes should be smaller for treated groups relative to the control group if respondents are Bayesian learners. If there is no difference in slopes between control and treatment groups, then the provided message is not informative for households. We will report $\hat{\beta}$ and $\hat{\gamma}$ for a treatment group relative to $\hat{\beta}$ and $\hat{\gamma}$ for the control group.

Specifications (1) and (2) utilize pre-treatment and post-treatment beliefs, but some survey responses are available only at the post-treatment stage. For these responses, we employ the following specification:

$$E_i^{post}(X) = \sum_{s=1}^{S} \beta_s \times Treatment_{s,i} + error. \quad (3)$$

Given that treatment assignment is random, specifications (1)–(3) do not require controls to account for respondents' heterogeneity to estimate treatment effects. Including controls only reduces standard errors and does not make material impact on our estimates (results are available upon request). To keep our analysis simple, we thus do not include controls in the reported results. To attenuate the adverse effects of extreme survey responses and, more generally, influential observations on our estimates, we winsorize data at the bottom and top 1 percent, drop implausible values (e.g., mortgage rates greater than 40 percent), and estimate specifications (1)–(3) using Huber (1964) robust regressions. Huber-robust regressions differ from using winsorized data in standard regressions because they also take correlations across variables into account.

4. Results

Using these empirical specifications, we now turn to how treatments affect households' beliefs and plans. We discuss each of these in turn.

4.1 Macroeconomic Expectations

Modern macroeconomic theory emphasizes the central role of expectations and the power of communicating policy actions to economic agents. Indeed, credible announcements about current or future policy are predicted to have large effects on perceptions and expectations about macroeconomic variables and thus influence firms' and households' choices. We now examine whether informing households about COVID-19 facts as well as policy actions taken in response by various government bodies can move households' expectations.

Table 3 reports results for specification (1). We generally find that the average size of belief revisions in the control group is economically small, with the only exception being inflation expectations (column 1). The large revision for inflation expectations reflects the fact that the pre-treatment expectations are elicited via a distribution question with pre-set upper and lower bounds at +/–12 percent similar to the wording in the Federal Reserve Bank of New York's Survey of Consumer Expectations, while post-treatment expectations are collected as point predictions.

We find that informing households about COVID-19 recovery (opposite of fatality) and contagion rates (treatment T6) generally has no material effect on expectations for inflation (column 1), the unemployment rate (columns 2 and 3), mortgage rates (columns 4–7), or households' expected income growth. Note that the vast majority of households is overly skeptical about the COVID-19 recovery and contagion rates and therefore this treatment presents a clear, one-sided surprise for households. While the estimated coefficients are statistically significant for the current mortgage rate and expected household income growth, the economic significance of these effects is very small. For example, this information treatment lowers households' expected income growth by 0.094 percentage point, which is smaller relative to the standard deviation of the belief revision in the control group (0.906 percentage point; column 8, bottom row, Table 3) by an order of magnitude. Our results are in line with the findings in Binder (2020) and Fetzer et al. (2020), who also document that randomized provision of COVID-19 health facts has at most a very modest (if any) effect on economic (personal or aggregate) expectations. These results are consistent with two views. One is that households are unable to

Table 3. Macroeconomic and Household-Level Expectations

				Unemployment Rate		Mortgage Rate				
Treatment	**Health Info Is Provided**	**Policy Response Is Provided**	**Inflation (1)**	**Short Run (2)**	**Long Run (3)**	**Current (4)**	**End of 2020 (5)**	**End of 2021 (6)**	**In 3–5 Years (7)**	**Household Income Growth (8)**
T1	No	No (Control Group)	2.442***	−0.024	−0.300***	0.003*	0.131***	0.064***	−0.007	0.124***
			(0.138)	(0.101)	(0.044)	(0.002)	(0.017)	(0.020)	(0.017)	(0.023)
	Relative to Control Group									
T2	No	Fed Actions	−0.691***	0.166	−0.034	−0.003	−0.084***	0.032	0.019	0.011
			(0.190)	(0.140)	(0.064)	(0.002)	(0.025)	(0.029)	(0.024)	(0.033)
T3	No	Congress Actions	0.360*	0.348**	0.089	−0.003	−0.032	0.025	−0.002	−0.076**
			(0.194)	(0.141)	(0.063)	(0.002)	(0.024)	(0.028)	(0.023)	(0.031)
T4	No	Fed and Congress Actions	−0.291	0.396***	−0.064	−0.005**	−0.074***	0.023	−0.003	−0.006
			(0.191)	(0.140)	(0.062)	(0.002)	(0.024)	(0.029)	(0.024)	(0.033)
T5	No	Health Officials	0.179	0.280**	0.016	−0.005**	−0.008	0.013	0.008	−0.043
			(0.195)	(0.138)	(0.063)	(0.002)	(0.025)	(0.029)	(0.023)	(0.033)
T6	Yes	No	−0.183	−0.056	0.061	−0.006***	−0.004	0.032	−0.004	−0.094***
			(0.190)	(0.138)	(0.060)	(0.002)	(0.024)	(0.028)	(0.023)	(0.030)
T7	Yes	Fed Actions	−0.137	0.250*	−0.081	−0.002	−0.062**	−0.056*	−0.031	0.020
			(0.196)	(0.142)	(0.063)	(0.002)	(0.025)	(0.029)	(0.025)	(0.034)
T8	Yes	Congress Actions	−0.253	−0.021	−0.060	−0.006***	0.042*	0.053*	0.020	−0.106***
			(0.190)	(0.139)	(0.065)	(0.002)	(0.025)	(0.029)	(0.023)	(0.032)
T9	Yes	Fed and Congress Actions	−0.000	0.050	−0.182***	−0.004*	−0.068***	−0.016	−0.038	0.033
			(0.192)	(0.142)	(0.063)	(0.002)	(0.024)	(0.029)	(0.024)	(0.034)
T10	Yes	Health Officials	−0.371**	−0.035	−0.022	−0.001	−0.027	−0.002	−0.010	−0.014
			(0.186)	(0.142)	(0.063)	(0.002)	(0.024)	(0.029)	(0.024)	(0.033)
Observations			12,248	11,716	11,412	8,433	11,389	11,639	11,302	9,351
R-squared			0.003	0.002	0.002	0.001	0.003	0.002	0.001	0.003
St. Dev. of Dep. Variable in Control Group			4.912	3.869	1.687	0.0720	0.645	0.743	0.640	0.906

Note: The table reports Huber-robust estimation of specification (1) for macroeconomic expectations. All dependent variables are measured in percent. Revisions in inflation expectations are measured as post-treatment inflation forecast prediction minus pre-treatment implied-mean inflation forecast. Inflation expectations is at the one-year horizon. Revisions in short-run unemployment expectations are measured as post-treatment unemployment rate expected at the end of 2020 minus pre-treatment one-year-ahead forecast of the unemployment rate. Revisions in long-run unemployment expectations are measured as post-treatment unemployment rate expected at the next three to five years minus pre-treatment unemployment rate expected in the three to five years. Revisions in mortgage rate expectations (perceptions) are measured as post-treatment expected mortgage rate for "a person with excellent credit" minus pre-treatment expected mortgage rate for "a person like you." Revision in household expected income is measured as post-treatment expectations (one year ahead; "How much higher or lower do you think your household's total net income will be over the next 12 months compared to the last 12 months? Please provide an answer in percentage terms.") minus pre-treatment expectations (one year ahead; "How much higher or lower do you think your household's total after-tax (i.e., 'take home') income will be over the next 12 months compared to the last 12 months? Please provide an answer in percentage terms."). Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

interpret health facts in a macroeconomic context, that is, they cannot draw a connection between the severity of COVID-19 and macroeconomic outcomes. The second viewpoint is that households believe that COVID-19 does not influence economic outcomes. This alternative view is unlikely to be empirically relevant. For example, Coibion, Gorodnichenko, and Weber (2020) document that households attribute pervasive, large losses in their income and wealth to the COVID-19 outbreak and that they are highly concerned about their financial situation because of the COVID-19 pandemic. Thus, we interpret this result as implying that households are unable to quickly draw connections between the severity of the disease and macroeconomic outcomes. One implication of this is that policy responses which focus on communicating about the disease and its health consequences cannot be expected to significantly affect households' economic expectations. Health communications cannot be a substitute for economic communications unless it clearly communicates how these health facts are relevant for individuals and the broader economy.

Appraising households of the Federal Reserve's actions (treatment T2) *lowers* inflation expectations by 0.7 percentage point. While one might have expected to see an increase in households' inflation expectations in response to this policy, our finding is consistent with Coibion, Georgarakos et al. (2020) documenting a positive co-movement of inflation and interest rate expectations unconditionally and in response to treatments with numeric inflation/interest rate information. Specifically, when the Fed lowers interest rates, households lower their inflation expectations, which could capture an "information effect" of policy announcements. Also in agreement with Coibion, Georgarakos et al. (2020), our estimates suggest that households do not believe in the ability of the Fed to influence the unemployment rate: treatment T2 has no discernable effect on the expected unemployment rate in either the short or long run (columns 2 and 3 in Table 3, respectively). Nor do we find any economic effect on the mortgage rate expectations: the estimated coefficients are close to zero. This result suggests that, given how low mortgage rates were by historical standards before the COVID-19 crisis, households may view the Fed's power to lower mortgage rates even further as limited. Finally, households do not observe a connection between monetary policy and their income growth. This latter result suggests that indirect effects of monetary policy on income expectations are weak in household surveys contrary to theoretical predictions in Heterogeneous Agent New Keynesian (HANK) models.

In contrast, informing households about the fiscal policy response ("Congress actions"; treatment T3) raises inflation expectations modestly by 0.3 percentage point. Interestingly, this treatment also raises short-run expectations for the unemployment rate (column 2) by a similar magnitude. This positive co-movement of inflation and unemployment ("stagflation") is consistent with Kamdar (2018): households tend to view high inflation as positively associated with high unemployment. It is also in line with the simple affective heuristic proposed in Andre et al. (2019). However, this fiscal policy action does not move households' longer-run expectations for the unemployment rate (column 3) or mortgage rate expectations (columns 4–7). Strikingly, although the fiscal policy action involves a direct transfer to households (which we provide in the treatment) and the vast majority of households participating in the survey qualify for these transfers, households do not view this policy as having a materially important effect on their expected income growth. In fact, the estimated coefficient is negative (column 8), again suggesting a potential information effect.

When we tell households about the fiscal *and* monetary policy response (treatment T4), the estimated responses are roughly a mix of responses to treatments T2 and T3. We do not observe any evidence suggesting that the policies reinforce each other. Similar to T2 and T3, treatment T4 does not generate economically large responses of macroeconomic expectations. This finding is particularly remarkable given that policy responses are enormous by historical standards and yet the American public treats these as largely irrelevant for the economy.

Treating people with information about good practices and the share of people under shelter-in-place orders (treatment T5) similarly has no noticeable effect on macroeconomic expectations. One might expect this treatment to have a pronounced effect on macroeconomic expectations if (i) households were not fully aware of how nationally pervasive lockdown orders were at the time and (ii) if households believed that lockdowns significantly affected economic activity. While we do not observe individuals' prior beliefs about the share of the U.S. population under lockdown at the time and therefore cannot test (i) directly, the fact that households were so uninformed about the recovery rates and transmission rates of the disease suggests that they were unlikely to be significantly more informed about lockdown policies. Thus, we interpret our finding of no effect from the health policy information treatment on households' macroeconomic expectations as indicative that they did not perceive lockdowns as very costly in economic terms.

One might anticipate that combining information on policy responses with health information on the severity of COVID-19 (treatments T7–T10) could alter how households translate policy responses into macroeconomic expectations. While we fail to find any marked difference in the responses of expectations for unemployment, mortgage rates, and income growth, we do observe several interesting facts for inflation expectations. First, the effect of the Fed's actions is considerably mitigated: when households were informed about the Fed policy response, they lowered their inflation expectations, but when households are also informed that COVID-19 is not as bad as they thought, the deflationary effect of the Fed policy response is largely gone (and is similar to the effect in response to information about only the recovery and contagion rates of COVID-19). Second, while the fiscal policy response ("Congress actions") raised inflation expectations, combining this response with health information lowers inflation expectations (although the effect is not statistically significant). Finally, providing information about COVID-19 recovery/contagion rate and information about CDC recommendations and the share of people under lockdown orders *lowers* inflation expectations. These results suggest that the broader context is important for inflation but other macroeconomic expectations are largely insensitive to information about health facts or policy responses.

To further explore the effect of treatments on macroeconomic expectations, we report estimated effects for specification (2) in Table 4 and visualize the distribution of post- and pre-treatment beliefs in Figures A.1–A.7 in the appendix. Column 1 of the table shows the results for inflation expectations. Note that the slope for the control group is 0.3 (rather than approximately 1) and the average revision (intercept) is 3.9 (rather than 0) because of the differences in the pre-treatment and post-treatment questions eliciting

Table 4. Macroeconomic and Household-Level Expectations (slope specification)

Health Info Is Provided	Policy Response Is Provided	Inflation (1)	Unemployment Rate: Short Run (2)	Unemployment Rate: Long Run (3)	Mortgage Rate: Current (4)	Mortgage Rate: End of 2020 (5)	Mortgage Rate: End of 2021 (6)	Mortgage Rate: In 3–5 Years (7)	Household Income Growth (8)
Intercept									
No	No (Control Group); T1	3.944***	1.496***	0.372***	0.002	0.252***	0.176***	0.104***	0.144***
		(0.122)	(0.157)	(0.074)	(0.001)	(0.028)	(0.034)	(0.032)	(0.027)
Relative to Control Group									
No	Fed Actions; T2	−0.668***	−0.311	0.173*	−0.003	−0.083**	−0.005	−0.021	0.020
		(0.165)	(0.207)	(0.102)	(0.002)	(0.040)	(0.045)	(0.041)	(0.038)
No	Congress Actions; T3	−0.018	−0.375*	−0.217**	−0.002	−0.069*	0.010	−0.046	0.112***
		(0.173)	(0.211)	(0.102)	(0.002)	(0.038)	(0.045)	(0.040)	(0.043)
No	Fed and Congress Actions; T4	−0.445***	−0.265	0.445***	−0.003	−0.145***	0.017	−0.059	−0.007
		(0.168)	(0.213)	(0.101)	(0.002)	(0.037)	(0.047)	(0.041)	(0.038)
No	Health Officials; T5	−0.104	−0.246	0.549***	−0.004**	−0.046	−0.008	0.015	−0.051
		(0.174)	(0.213)	(0.103)	(0.002)	(0.039)	(0.046)	(0.044)	(0.038)
Yes	No; T6	−0.483***	−0.363*	−0.364***	−0.005**	−0.098***	−0.038	−0.068*	−0.110***
		(0.167)	(0.208)	(0.096)	(0.002)	(0.036)	(0.043)	(0.039)	(0.036)
Yes	Fed Actions; T7	−0.300*	0.005	0.642***	0.000	−0.097**	−0.095**	−0.054	0.105**
		(0.172)	(0.215)	(0.102)	(0.002)	(0.039)	(0.045)	(0.044)	(0.044)
Yes	Congress Actions; T8	−0.640***	−0.209	0.496***	−0.005***	−0.005	0.033	−0.008	−0.127***
		(0.166)	(0.214)	(0.106)	(0.002)	(0.038)	(0.045)	(0.041)	(0.038)
Yes	Fed and Congress Actions; T9	−0.652***	−0.156	−0.183*	−0.003	−0.103***	−0.059	−0.054	0.031
		(0.168)	(0.219)	(0.104)	(0.002)	(0.038)	(0.044)	(0.042)	(0.039)
Yes	Health Officials; T10	−0.617***	0.046	0.762***	−0.000	−0.068*	0.058	−0.043	−0.015
		(0.171)	(0.223)	(0.096)	(0.002)	(0.037)	(0.051)	(0.043)	(0.039)

(*continued*)

Table 4. (Continued)

Health Info Is Provided	Policy Response Is Provided	Inflation (1)	Unemployment Rate: Short Run (2)	Unemployment Rate: Long Run (3)	Mortgage Rate: Current (4)	Mortgage Rate: End of 2020 (5)	Mortgage Rate: End of 2021 (6)	Mortgage Rate: In 3–5 Years (7)	Household Income Growth (8)
Slope									
No	No (Control Group); T1	0.300***	0.849***	0.887***	1.000***	0.970***	0.975***	0.977***	1.000***
		(0.024)	(0.013)	(0.011)	(0.000)	(0.005)	(0.006)	(0.006)	(0.002)
Relative to Control Group									
No	Fed Actions; T2	−0.124***	0.043**	−0.042***	0.000	0.001	0.009	0.010	−0.003
		(0.032)	(0.017)	(0.015)	(0.000)	(0.008)	(0.008)	(0.007)	(0.003)
No	Congress Actions; T3	0.033	0.073***	0.058***	0.000	0.008	0.003	0.010	−0.484***
		(0.034)	(0.018)	(0.014)	(0.000)	(0.008)	(0.008)	(0.007)	(0.008)
No	Fed and Congress Actions; T4	−0.046	0.062***	−0.095***	0.000	0.018***	0.001	0.013**	−0.001
		(0.033)	(0.017)	(0.014)	(0.000)	(0.006)	(0.009)	(0.007)	(0.003)
No	Health Officials; T5	0.016	0.051***	−0.116***	0.000*	0.008	0.005	−0.000	−0.003
		(0.036)	(0.018)	(0.015)	(0.000)	(0.008)	(0.008)	(0.008)	(0.003)
Yes	No; T6	−0.007	0.030*	0.075***	0.000	0.023***	0.017**	0.014**	−0.003
		(0.033)	(0.018)	(0.013)	(0.000)	(0.006)	(0.007)	(0.006)	(0.003)
Yes	Fed Actions; T7	−0.102***	0.020	−0.149***	0.000	0.009	0.009	0.005	−0.369***
		(0.033)	(0.018)	(0.015)	(0.000)	(0.007)	(0.008)	(0.008)	(0.008)
Yes	Congress Actions; T8	0.077**	0.038**	−0.114***	0.000*	0.013*	0.005	0.008	−0.004
		(0.033)	(0.018)	(0.015)	(0.000)	(0.007)	(0.008)	(0.007)	(0.003)
Yes	Fed and Congress Actions; T9	0.009	0.016	0.005	0.000	0.008	0.011	0.005	−0.006*
		(0.034)	(0.018)	(0.015)	(0.000)	(0.007)	(0.008)	(0.007)	(0.003)
Yes	Health Officials; T10	0.085**	−0.024	−0.165***	0.000	0.012*	−0.012	0.008	−0.002
		(0.034)	(0.019)	(0.013)	(0.000)	(0.006)	(0.009)	(0.007)	(0.003)
Observations		12,048	10,012	11,186	7,977	11,314	11,504	11,173	9,598
R-squared		0.147	0.866	0.913	1.000	0.976	0.969	0.977	0.982
St. Dev. of Dep. Variable in Control Group		4.344	8.554	5.739	4.102	3.619	3.856	3.264	9.185

Note: The table reports Huber-robust estimation of specification (2) for macroeconomic expectations. All dependent variables are measured in percent. See notes to Table 3 for definitions of variables. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

inflation expectations (distribution versus point prediction). Relative to this benchmark, we find that the estimated "level" effects (i.e., coefficients β in specification (2)) tend to be negative. These results suggest that the received signals are interpreted by households as providing information that is below the average initial beliefs of households. At the same time, the slope effects tend to be close to zero in economic terms, although some coefficients are statistically different from zero. Therefore, the treatments generally shift the distribution of inflation expectations to the left without a discernible change in the cross-sectional variation in expectations. Interestingly, while some information treatment may be conceived as disinflationary, the monetary and fiscal policies that employed a wide arsenal of tools to fight the COVID-19 crisis are hardly disinflationary by themselves. This reaction to treatments thus appears to be consistent with significant information effects, that is, households could interpret strong policy responses as signaling a confirmation of an economic catastrophe.

Short-term unemployment rate expectations (column 2 of Table 4) show little "level" or "slope" reaction to the treatments. In contrast, longer-term expectations (column 3) have some variation in the "level" effect, ranging from a 0.762 percentage point increase for treatment T10 (COVID facts and health information) to a −0.364 percentage point decrease for treatment T5 (COVID facts only). The slope effects are generally negative, suggesting some compression in the post-treatment disagreement across respondents. Consistent with the results in Table 3, we find no material "level" or "slope" response in expectations for mortgage rates (columns 4–7 of Table 4). Similarly, there is generally little variation in response to treatments for households' income growth (column 8 of Table 4).

In summary, our results suggest that while inflation expectations have some limited sensitivity to information treatments, other macroeconomic expectations (especially, expectations for mortgage rates) do not exhibit any discernible reaction to the provided information. Given that households are (on average) poorly informed about macroeconomic policies or health facts and that the benefits of having access to information about the enormous policy responses as well as health facts are predicted to be high by mainstream macroeconomic theory, this weak (if any) reaction to the information treatments is indeed striking.

4.2 Labor Market Expectations

We now consider how these treatments affect households' expectations for their labor market outcomes, specifically the probability of keeping their job if employed and the probability of finding a job if unemployed. Because we do not have pre-treatment measures of these subjective probabilities, we use specification (3) to estimate the effect of information treatments on perceived labor market outcomes. We find (Table 5) that information treatments do not have a materially important effect on the subjective probability of losing a job (column 1): the estimated coefficients are small (fractions of a percentage point) and generally not significant statistically. In contrast, when it comes to how the unemployed perceive the probability of finding a job, the provision of COVID-19 facts (treatment T6) raises this perceived probability by 20 percentage points, a large effect. Interestingly, any other treatment, including treatments where information about COVID-19 facts is combined with information on policy responses, generate no statistically significant effect on the perceived probability of finding a job. This pattern appears to suggest two conclusions. First, households do not view policy responses as having an important effect on their labor market outcome. Second, providing basic COVID-19 facts appears to be helpful in making unemployed households less pessimistic about their labor market prospects—thus suggesting some role for information campaigns highlighting public health implications of the COVID-19 outbreak—but the information effect in the policy response seems to offset this positive effect.

4.3 Planned Consumer Spending

Coibion, Gorodnichenko, and Weber (2020) and Dietrich et al. (2020) document that, during the COVID-19 crisis, households significantly downgraded their plans to buy durable goods such as houses/apartments, cars, and large appliances. In part, the policy response to the crisis was aimed at making households more enthusiastic about purchases of durable goods. For example, policy interest rates where cut down to zero and new rounds of quantitative easing reduced mortgage rates, thus making the financial cost of durable purchases more enticing. However, it remains unclear to what extent

Table 5. Probability of Losing a Job or Finding a Job

Treatment	Health Info. Is Provided	Policy Response Is Provided	Probability of Losing a Job (1)	Probability of Finding a Job (2)
T1	No	No (Control Group)	0.961***	45.853***
			(0.088)	(3.909)
	Relative to Control Group			
T2	No	Fed Actions	0.245*	2.638
			(0.135)	(5.575)
T3	No	Congress Actions	0.086	−2.978
			(0.130)	(5.791)
T4	No	Fed and Congress Actions	−0.188	6.957
			(0.115)	(5.444)
T5	No	Health Officials	−0.071	−2.930
			(0.121)	(5.934)
T6	Yes	No	0.015	20.138***
			(0.125)	(6.125)
T7	Yes	Fed Actions	0.011	−1.574
			(0.126)	(5.678)
T8	Yes	Congress Actions	−0.030	2.962
			(0.125)	(5.691)
T9	Yes	Fed and Congress Actions	0.149	6.608
			(0.132)	(5.971)
T10	Yes	Health Officials	0.129	7.017
			(0.131)	(5.943)
Observations			5,084	894
R-squared			0.002	0.031
St. Dev. of Dep. Variable in Control Group			2.414	34.98

Note: The table reports Huber-robust estimation of specification (3) for expected labor market outcomes. All dependent variables are measured in percent ranging from 0 to 100. The sample for column 3 includes only employed (at the time of the survey) people. The sample for column 2 includes only unemployed (don't have a job and look for a job at the time of the survey) people. Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

these policies turned the tide of pessimism and encouraged purchases of new goods.[3] To gauge the influence of these policies on

[3]At the same time, historically low rates did generate a wave of mortgage refinances. According to information from the Mortgage Bankers Association, refinances increased to $1.5 trillion as of early May, a 51 percent jump compared to 2019.

consumer spending, we asked respondents at the post-treatment stage to report whether it is a good time to buy a durable good. Specifically, respondents can report their beliefs on a scale of 1 (very good time) to 5 (very bad time).

Using specification (3), we find (Table 6) that information treatments generally make households more positive about buying a house (the coefficients are negative), but the magnitude of the response is quite small. The largest responses are approximately −0.1 to −0.15, while the scale varies from 1 to 5 and the standard deviation of scores in the control group is approximately one. The views for car or appliance purchases in response to the treatments are more mixed, with some treatments resulting in less positive views and some treatments resulting in more positive views. However, the economic magnitudes remain rather small. These results suggest that although informing households about policies or health facts is somewhat helpful in improving consumer sentiment, the effects are modest at best, thus again pointing to limited effectiveness of information provision on economic outcomes.

4.4 Policy Approval

While consumers seem to not understand the economic implications of the policy responses, they may still appreciate the reaction of various government bodies to the crisis. To measure this potential effect, we ask respondents to rate the actions of the President, the Congress, the Federal Reserve, and U.S. health officials by answering the following question on a scale running from 0 (not helpful at all) to 10 (extremely helpful): "How much do you trust the actions taken by [GOVERNMENT BODY] will be helpful for you? And the overall American population?" Note that we ask households to assess the value of the actions for them personally and for the country as a whole so that we can get a metric—however imperfect—about the ability of households to grasp partial-equilibrium and general-equilibrium effects.

For the control group, U.S. health officials have the highest scores (the averages are 6.3 for the country and 6.1 for the respondent), followed by the Fed (5.6 for the country and 5.0 for the respondent), the President (4.9 for the country and 4.6 for the respondent), and then Congress (4.5 for the country and 4.3 for the respondent).

Table 6. Good Time To Buy a Durable Good

Treatment	Health Info. Is Provided	Policy Response Is Provided	House (1)	Car (2)	Appliance (3)
T1	No	No (Control Group)	3.023***	3.019***	3.031***
			(0.029)	(0.028)	(0.016)
	Relative to Control Group				
T2	No	Fed Actions	−0.003	0.074*	−0.023
			(0.040)	(0.040)	(0.024)
T3	No	Congress Actions	0.076*	0.138***	0.041*
			(0.040)	(0.040)	(0.024)
T4	No	Fed and Congress Actions	−0.106***	0.076*	−0.008
			(0.040)	(0.040)	(0.024)
T5	No	Health Officials	−0.112***	−0.119***	−0.096***
			(0.040)	(0.040)	(0.024)
T6	Yes	No	0.016	0.014	−0.063***
			(0.040)	(0.040)	(0.023)
T7	Yes	Fed Actions	0.002	0.047	−0.019
			(0.040)	(0.040)	(0.023)
T8	Yes	Congress Actions	−0.144***	0.016	−0.006
			(0.040)	(0.040)	(0.024)
T9	Yes	Fed and Congress Actions	0.053	0.081**	0.018
			(0.040)	(0.040)	(0.023)
T10	Yes	Health Officials	−0.054	0.088**	0.005
			(0.040)	(0.040)	(0.023)
Observations			13,761	13,761	13,210
R-squared			0.005	0.004	0.003
St. Dev. of Dep. Variable in Control Group			1.021	1.022	0.664

Note: The table reports Huber-robust estimation of specification (3) for whether it is a good time to buy a durable. All dependent variables are measured in percent ranging from 1 (very good time) to 5 (very bad time). Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1, 5, and 10 percent level, respectively.

Households consistently perceive policy institutions as being better for the country than for them personally. At the same time, we observe a high correlation (ranging from 0.7 for the Fed to 0.9 for the President) between responses for personal and country-level implications and much weaker correlation between assessment for various government bodies (e.g., the correlation between personal effect from the President's actions and the Fed's actions is 0.3), thus suggesting that households differentiate actions of various government branches during the crisis.

Information treatments have highly heterogeneous effects on these scores. Using specification (3), we find (columns 1 and 2 of Table 7) that information about actual policies does not improve approval of the President's actions. If anything, treatments T2 (monetary policy) and T4 (monetary and fiscal policy) reduce the approval of the President's actions. These results are consistent with the view that respondents generally have strong priors about the President. In contrast, *every* treatment raises the appreciation of Congress. This includes treating households with information about monetary policy which is not controlled (at least directly) by the Congress. The Federal Reserve is viewed less positively when households are informed about monetary policy (treatment T2), but the Fed gets some credit for fiscal policy. The views on the actions of U.S. health officials are weakly improved by the treatments when respondents are informed about basic COVID-19 facts. The latter observation suggests that when households are told that COVID-19 is not as contagious and fatal as they think initially, they tend to credit U.S. health officials.

While treatment effects are statistically significant, the economic significance of the effects varies. For example, treatments can materially improve the image of Congress, while views on the President's actions appear to be rather unresponsive to the provided information. Thus, similar to the responses of macroeconomic expectations, consumer expenditure plans, and labor market expectations, the perceptions of policy effectiveness show some reaction to information treatments, but the effects range from zero to modest. This is again consistent with the notion that the general public is rather confused about the responsibilities of various government bodies as well as implications of the bodies' actions. Specifically, fiscal and monetary policies get fairly little credit.

Table 7. Policy Evaluation

Treatment	Health Info	Policy Info	President You (1)	President U.S. (2)	Congress You (3)	Congress U.S. (4)	Federal Reserve You (5)	Federal Reserve U.S. (6)	Health Officials You (7)	Health Officials U.S. (8)
			How much do you trust the actions taken by the [government bank] will be helpful for {you, U.S.}?							
T1	No	No (Control Group)	4.522***	4.875***	4.241***	4.641***	5.184***	5.798***	6.390***	6.645***
			(0.103)	(0.100)	(0.059)	(0.055)	(0.049)	(0.048)	(0.056)	(0.053)
	Relative to Control Group									
T2	No	Fed Actions	−0.263*	−0.294**	0.179**	0.258***	−0.212***	−0.004	0.001	−0.070
			(0.146)	(0.143)	(0.082)	(0.076)	(0.069)	(0.068)	(0.081)	(0.077)
T3	No	Congress Actions	0.059	−0.016	0.216***	0.165**	0.160**	0.066	0.035	−0.001
			(0.147)	(0.142)	(0.083)	(0.078)	(0.069)	(0.069)	(0.081)	(0.077)
T4	No	Fed and Congress Actions	−0.311**	−0.417***	0.279***	0.274***	−0.127*	0.084	−0.047	0.059
			(0.147)	(0.143)	(0.083)	(0.077)	(0.070)	(0.069)	(0.080)	(0.076)
T5	No	Health Officials	−0.169	−0.229	0.172**	0.168**	−0.044	−0.203***	0.073	0.041
			(0.147)	(0.143)	(0.082)	(0.077)	(0.069)	(0.066)	(0.080)	(0.076)
T6	Yes	No	−0.038	−0.069	0.180**	0.075	0.007	−0.006	0.100	0.118
			(0.147)	(0.143)	(0.081)	(0.076)	(0.068)	(0.068)	(0.079)	(0.075)
T7	Yes	Fed Actions	0.184	0.173	0.200**	0.336***	−0.071	0.167**	0.106	0.127*
			(0.145)	(0.142)	(0.083)	(0.078)	(0.069)	(0.069)	(0.080)	(0.076)
T8	Yes	Congress Actions	−0.064	−0.097	0.495***	0.405***	0.209***	0.191***	0.361***	0.279***
			(0.147)	(0.143)	(0.082)	(0.076)	(0.069)	(0.068)	(0.080)	(0.076)
T9	Yes	Fed and Congress Actions	0.003	−0.003	0.570***	0.570***	0.213***	0.293***	0.115	0.073
			(0.145)	(0.141)	(0.082)	(0.078)	(0.068)	(0.069)	(0.080)	(0.076)
T10	Yes	Health Officials	−0.045	−0.088	0.050	0.130*	−0.000	0.050	0.175**	0.164**
			(0.147)	(0.143)	(0.083)	(0.078)	(0.070)	(0.068)	(0.080)	(0.076)
Observations			13,521	13,521	13,473	13,467	13,346	13,299	13,423	13,376
R-squared			0.002	0.002	0.006	0.006	0.005	0.005	0.003	0.002
St. Dev. of Dep. Variable in Control Group			3.391	3.336	2.152	2.069	1.882	1.767	1.986	1.872

Note: The table reports Huber-robust estimation of specification (3) for political approval of policies implemented by various government bodies. All dependent variables are measured on the scale ranging from 0 (not helpful at all) to 10 (extremely helpful). Robust standard errors are in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

5. Discussion and Concluding Remarks

Understanding the way in which policy actions affect the economy has long been a challenge for macroeconomists. Standard models imply that households' expectations play a large role in driving these effects, as households incorporate the announcements into their expectations and their decisions. Our results challenge this key mechanism: we find little evidence that even large policy decisions have much of an effect on households' economic expectations or their planned actions. This result obtains for both monetary and fiscal policies during the COVID-19 crisis, and extends to some of the health recommendations made by the federal government as well.

This result is in the same spirit as recent work documenting pervasive inattention on the part of households and firms to monetary policy actions and announcements. However, it goes beyond inattention because we directly inform participants about recent and dramatic policy decisions, yet even this directly provided information has essentially no effect on household beliefs. Perhaps, cognitive constraints as modeled in Angeletos and Lian (2018), Farhi and Werning (2019), Woodford (2019), and Gabaix (2020) and the singular nature of COVID-19 limit the ability of households to reason through the implications of the pandemic and policy responses (see, e.g., Iovino and Sergeyev 2020 for an application of this notion to quantitative easing) and, as a result, inattention and cognitive constraints reinforce each other in dampening the response of beliefs and hence economic outcomes to policy announcements.

Another feature of our results that differs from prior work on inattention is the fact that our information treatments have little effect on households' macroeconomic expectations. Other work has documented that when households are told about recent inflation rates or the central bank's inflation target, their macroeconomic expectations change sharply (e.g., Coibion, Gorodnichenko, and Weber 2019). Here, our focus is on policy interventions involving monetary, fiscal, and health policies, none of which induce significant revisions in beliefs. Given the evidence from prior work that households' macroeconomic expectations respond strongly to simple information treatments during normal times, our results should not be driven by the possibility that households do not care about macroeconomic outcomes. Instead, they are judging that the policy announcements do not change their macroeconomic outlooks. This could reflect a belief that policy interventions themselves are ineffective or a belief that the interventions are offsetting even more pronounced economic weakness than what they initially anticipated, i.e., the information effect cancels out the effect of the policy intervention on beliefs.

Our results are also distinct from and complementary to Andre et al. (2019), who study how households respond to *exogenous* fiscal and monetary policy actions: we explicitly describe the policy treatments as an *endogenous* response to the COVID-19 crisis. Taken together, these results point toward a world in which policy shocks have non-trivial effects on household expectations and actions while systematic policy decisions have much smaller (if any) effects, which is the complete opposite of what we tend to observe in standard macroeconomic models in which systematic policy is close to all-powerful while policy shocks have much smaller effects. We view this as a fundamental challenge to workhorse models used by macroeconomists in which the rapid and endogenous adjustment of household expectations is a key driver of macroeconomic outcomes.

References

Andre, P., C. Pizzinelli, C. Roth, and J. Wohlfart. 2019. "Subjective Models of the Macroeconomy: Evidence from Experts and a Representative Sample." Manuscript.

Angeletos, G.-M., and C. Lian. 2018. "Forward Guidance without Common Knowledge." *American Economic Review* 108 (9): 2477–2512.

Armona, L., A. Fuster, and B. Zafar. 2019. "Home Price Expectations and Behavior: Evidence from a Randomized Information Treatment." *Review of Economic Studies* 86 (4): 1371–1410.

Bachmann, R., T. Berg, and E. Sims. 2015. "Inflation Expectations and Readiness to Spend: Cross-Sectional Evidence." *American Economic Journal: Economic Policy* 7 (1): 1–35.

Binder, C. 2020. "Coronavirus Fears and Macroeconomic Expectations." *Review of Economics and Statistics* 102 (4): 721–30.

Campbell, J., C. Evans, J. Fisher, and A. Justiniano. 2012. "Macroeconomic Effects of Federal Reserve Forward Guidance." *Brookings Papers on Economic Activity* 44 (1, Spring): 1–80.

Cavallo, A., G. Cruces, and R. Perez-Truglia. 2017. "Inflation Expectations, Learning, and Supermarket Prices: Evidence from Survey Experiments." *American Economic Journal: Macroeconomics* 9 (3): 1–35.

Coibion, O., D. Georgarakos, Y. Gorodnichenko, and M. van Rooij. 2019. "How Does Consumption Respond to News about Inflation? Field Evidence from a Randomized Control Trial." NBER Working Paper No. 26106.

Coibion, O., D. Georgarakos, Y. Gorodnichenko, and M. Weber. 2020. "Forward Guidance and Household Expectations." NBER Working Paper No. 26778.

Coibion, O., Y. Gorodnichenko, and S. Kumar. 2018. "How Do Firms Form Their Expectations? New Survey Evidence." *American Economic Review* 108 (9): 2671–2713.

Coibion, O., Y. Gorodnichenko, S. Kumar, and M. Pedemonte. 2020. "Inflation Expectations as a Policy Tool?" *Journal of International Economics* 124 (May): Article 103297.

Coibion, O., Y. Gorodnichenko, and M. Weber. 2019. "Monetary Policy Communications and their Effects on Household Inflation Expectations." NBER Working Paper No. 25482.

———. 2020. "The Cost of the Covid-19 Crisis: Lockdowns, Macroeconomic Expectations, and Consumer Spending." NBER Working Paper No. 27141.

D'Acunto, F., A. Fuster, and M. Weber. 2021. "Diverse Policy Committees Can Reach Underrepresented Groups." Manuscript.

D'Acunto, F., D. Hoang, M. Paloviita, and M. Weber. 2019. "Cognitive Abilities and Inflation Expectations." *AEA Papers and Proceedings* 109 (May): 562–66.

———. 2020. "Effective Policy Communication: Targets versus Instruments." Manuscript.

———. 2021. "IQ, Expectations, and Choice." Forthcoming in *Review of Economic Studies*.

D'Acunto, F., D. Hoang, and M. Weber. 2021. "Managing Households' Expectations with Unconventional Policies." Forthcoming in *Review of Financial Studies*.

D'Acunto, F., U. Malmendier, J. Ospina, and M. Weber. 2021. "Exposure to Grocery Prices and Inflation Expectations." *Journal of Political Economy* 129 (5): 1615–39.

D'Acunto, F., U. Malmendier, and M. Weber. 2020. "Gender Roles Produce Divergent Economic Expectations." *Proceedings of the National Academy of Sciences* 118 (21): 1–10.

Dietrich, A. M., K. Kuester, G. J. Muller, and R. S. Schoenle. 2020. "News and Uncertainty about COVID-19: Survey Evidence and Short-run Economic Impact." Manuscript.

Farhi, E., and I. Werning, 2019. "Monetary Policy, Bounded Rationality, and Incomplete Markets." *American Economic Review* 109 (11): 3887–3928.

Fetzer, T., L. Hensel, J. Hermle, and C. Roth. 2020. "Perceptions of Contagiousness and Mortality of COVID-19 Shape Economic Sentiment." Manuscript.

Gabaix, X. 2020. "A Behavioral New Keynesian Model." *American Economic Review* 110 (8): 2271–2327.

Huber, P. J. 1964. "Robust Estimation of a Location Parameter." *Annals of Mathematical Statistics* 35 (1): 73–101.

Iovino, L., and D. Sergeyev. 2018. "Central Bank Balance Sheet Policies Without Rational Expectations." CEPR Discussion Paper No. 13100.

Kamdar, R. 2018. "The Inattentive Consumer: Sentiment and Expectations." Manuscript.

Lamla, M., and D. Vinogradov. 2019. "Central Bank Announcements: Big News for Little People?" *Journal of Monetary Economics* 108 (December): 21–38.

Romer, C. D., and D. H. Romer. 2004. "A New Measure of Monetary Shocks: Derivation and Implications." *American Economic Review* 94 (4): 1055–84.

———. 2010. "The Macroeconomic Effects of Tax Changes: Estimates Based on a New Measure of Fiscal Shocks." *American Economic Review* 100 (3): 763–801.

Woodford, M. 2005. "Central Bank Communication and Policy Effectiveness." In *The Greenspan Era: Lessons for the Future.* Proceedings of Economic Policy Symposium sponsored by the Federal Reserve Bank of Kansas City, held in Jackson Hole, Wyoming, August 25–27.

———. 2019. "Monetary Policy Analysis When Planning Horizons Are Finite." *NBER Macroeconomics Annual 2018*, Vol. 33, ed. M. Eichenbaum and J. A. Parker, 1–50 (chapter 1). Chicago: University of Chicago Press.

Monetary Policy and COVID-19*

Michał Brzoza-Brzezina,[a] Marcin Kolasa,[a,b] and
Krzysztof Makarski[a,c]
[a]SGH Warsaw School of Economics
[b]International Monetary Fund
[c]FAME|GRAPE

We study the macroeconomic effects of the COVID-19 epidemic in a quantitative dynamic general equilibrium setup with nominal rigidities. First, we evaluate various containment policies and show that they allow to dramatically reduce the welfare cost of the disease. Then we investigate the role that monetary policy, in its capacity to manage aggregate demand, should play during the epidemic. According to our results, treating the observed output contraction as a standard recession leads to a bad policy, irrespective of the underlying containment measures. We evaluate how monetary policy should resolve the trade-off between stabilizing the economy and containing the epidemic. We find that containment policies and monetary policy are complementary. If no administrative restrictions are implemented, the second motive prevails, and, despite the deep recession, optimal monetary policy is contractionary. Conversely, if sufficient containment measures are introduced, central bank interventions should be expansionary and help stabilize economic activity.

JEL Codes: E1, E5, E6, H5, I1, I3.

*The authors thank Julia Jabłońska for outstanding research assistance and Yang Zhang for providing an excellent discussion. Comments and suggestions received from Christopher Erceg, Luc Laeven, Jesper Lindé, an anonymous referee, and participants of the IJCB conference "The Macroeconomic Consequences of COVID-19," the Warsaw Economic Seminar, and the internal seminar at the IMF are gratefully acknowledged as well. This project was financed by the National Science Centre grant No. 2020/37/B/HS4/00399. The previous version of this paper was published as IMF Working Paper No. 2021/274. The views presented herein are those of the authors and not those of the institutions with which they are affiliated. Author e-mails: mbrzez@sgh.waw.pl, mkolas@sgh.waw.pl, and kmakar@sgh.waw.pl.

1. Introduction

The COVID-19 pandemic poses an unprecedented challenge for both health and economic policy. The two are strongly interrelated, as policies that aim at mitigating the spread of the disease, like various forms of lockdown or isolation, have mostly negative consequences for economic activity. Furthermore, governments in many countries applied fiscal stimuli of unprecedented scale to prevent persistent loss of production potential, a wave of bankruptcies, financial instability, and an increase in economic inequality. These efforts were strongly supported by ultra-loose monetary policy, which included sharp cuts of nominal interest rates and large-scale purchases of government debt by central banks. These actions were much needed, as they probably helped avoid a complete breakdown of the economic system. However, their direct and indirect effect on aggregate demand, and hence on the intensity of economic interactions by agents, might also have had a non-negligible effect on the pandemic dynamics.

This non-standard and unexplored dimension of macroeconomic stabilization policies poses a considerable challenge to the theory and practice of economics, especially that there is minimal past experience with economic interventions during an epidemic. In particular, it is far from obvious how monetary policy should react beyond its efforts to preserve financial stability and (possibly) support financing appropriately calibrated fiscal packages. A typical central bank reaction to a recession is to provide monetary stimulus, thus minimizing the drop in economic activity. However, engineering an aggregate demand expansion can prove counterproductive in times of the pandemic since the recession reflects, to a large extent, an intentional and desired reduction in economic activity. This results from the actions of agents who want to decrease the risk of catching the disease, and of policymakers who impose lockdowns and other measures to contain the virus. Therefore, optimal aggregate demand management must resolve a trade-off between addressing aggregate demand externalities due to nominal rigidities, which typically call for a policy stimulus during recessions, and agents' failure to internalize the impact of their actions on pandemics, which may suggest an opposite reaction. Prominent policymakers and economists have raised doubts of this nature (see, e.g., Bullard 2020 and Kaplan, Moll, and

Violante 2020). However, to our knowledge, a quantitative analysis of this dilemma in a monetary policy context is still missing, and this is where we see our main contribution.

Against this backdrop, we propose a quantitative analytical framework that connects two modeling concepts. The first is a standard microfounded business cycle model that allows discussing the effects of monetary policy in its capacity to manage aggregate demand. The second is an epidemic modeling setup that allows simulating a pandemic resembling COVID-19. We thus obtain a natural platform that enables experimenting with different policy options and evaluating their welfare effects, including a two-way relationship between economic activity and the spread of the pandemic. Four findings stand out in the context of monetary policy. First, if no administrative restrictions are in place, then monetary policy should, in fact, be contractionary, i.e., cool down the economy, flatten the infection curve, and thus save lives. This indicates that, under a laissez-faire approach to the pandemic, New Keynesian aggregate demand externalities are less important than externalities associated with agents' reactions to the pandemic.

Second, if the authorities introduce sufficiently tough lockdowns, aggregate demand management considerations come back to the forefront, and optimized monetary policy becomes expansionary. Hence, our findings support the stimulative reaction adopted by most central banks.

Third, irrespective of the containment measures in place, monetary policy should not follow the strategy of reacting to the pandemic-driven recession with the usual strength that is appropriate over the standard business cycle. Given the deep contraction in economic activity, such policy always results in a very strong monetary expansion, generating a positive (welfare-relevant) output gap, increasing the death toll, and lowering welfare. Fourth, the policy frontier between stabilizing the economy and reducing the death toll is flat for monetary policy compared with administrative containment measures. This means that central bank actions are not efficient at fighting COVID-19, but can relatively effectively limit the economic consequences of lockdowns if they are introduced on an appropriate scale.

The rest of this paper is organized as follows. Section 2 discusses how our study relates to the existing literature. In Section 3, we present our theoretical framework. Section 4 discusses the calibration. In Section 5, we present our main results. Section 6 concludes.

2. Literature Review

Our study is most closely related to the literature that attempts to model optimal epidemic policies and their economic consequences. Several papers use stylized frameworks to study the trade-off between lives saved due to lockdowns and economic costs associated with them. Atkeson (2020) compares several scenarios of suppressing the disease through social distancing. Alvarez, Argente, and Lippi (2020) formulate a simple planning problem to design an optimal lockdown limiting the spread of the disease. Acemoglu et al. (2020) extend their framework to account for multiple age groups. Finally, Favero, Ichino, and Rustichini (2020) study optimal lockdowns in a stylized economy with multiple sectors and age groups.

An increasing body of the literature implements general equilibrium models to study the optimal public policy response to the pandemic. Eichenbaum, Rebelo, and Trabandt (2020b) modify the standard SIR (susceptible, infected, recovered) setup by making the probability of infection explicitly dependent on economic decisions made by optimizing agents. They study trade-offs between public health and the economic cost of the pandemic. Jones, Philippon, and Venkateswaran (2020) employ a similar framework to study optimal mitigation policies in a pandemic. Glover et al. (2020) introduce a quantitative model to examine the interaction between macro-mitigation and micro-redistribution to find that optimal mitigation involves a mixture of such policies. Azzimonti et al. (2020) study infection dynamics and reopening scenarios in a heterogeneous sectors and household network model. Kaplan, Moll, and Violante (2020) argue that the government policy must face trade-offs between lives and livelihoods and over who should bear the burden of the economic costs. The view that there is a trade-off between health and the economy is challenged by Bodenstein, Corsetti, and Guerrieri (2020), who show that social distancing measures can reduce large upfront costs of the pandemic and slow down its spread. Krueger, Uhlig, and Xie (2021) argue that endogenous shifts in private consumption behavior across sectors of the economy can act as a potent mitigation mechanism during an epidemic or when the economy is reopened after a temporary lockdown.

In contrast to the considerable effort of modeling optimal containment policies, the question of how monetary policy should behave during an epidemic has not received much attention so far. Levin and Sinha (2020) use a simple New Keynesian framework to find that forward guidance has only tenuous net benefits. Lepetit and Fuentes-Albero (2021) study the effects of an unanticipated decline in the interest rate to conclude that monetary policy is likely to be ineffective at the height of the pandemic. Still, it should help sustain the recovery in economic activity once the virus starts dissipating. Vásconez, Damette, and Shanafelt (2021) augment the DSGE-SIR model with a financial sector as in Gertler and Karadi (2011). They find that while standard monetary policy has a negligible effect on GDP during pandemics, unconventional monetary policy has the potential to lessen total losses in GDP. However, in contrast to our paper, neither of these studies focuses on the optimal response of monetary policy nor considers the fact that boosting economic activity can affect the spread of the disease.

On the modeling front, our paper connects two streams of the literature. First, we build on the most popular way of modeling epidemics. It draws from the seminal contribution of Kermack and McKendrick (1927) and its extension for the presence of asymptomatic infected agents (Prem et al. 2020). Second, we integrate this modified SIR framework, A-SIR, with the workhorse New Keynesian business cycle model (Clarida, Galí, and Gertler 1999). Our complete framework is most similar to Eichenbaum, Rebelo, and Trabandt (2020a), who show that a DSGE model with a SIR component has the desired features to study macroeconomic processes during an epidemic. However, our framework features important extensions. First, as mentioned above, we allow some infected agents to be carriers of the disease but experience no symptoms and be unaware of their infection. This modification makes the model more realistic and challenges public policy, since the isolation of all infected individuals is not feasible. Second, we allow agents to borrow from each other so that credit market conditions affect agents' balance sheets.

3. Model

As discussed above, our model connects an epidemic framework with a standard New Keynesian setup. From the epidemic perspective, agents belong to one of the following groups: susceptible, infected (symptomatic or asymptomatic), or recovered (from being formerly symptomatic or asymptomatic). Regarding their economic activity, they decide on consumption and labor supply and can borrow from each other. Firms operate in a monopolistically competitive environment and set prices in a staggered fashion, which means that monetary policy can affect real allocations. Additionally, the government conducts epidemic containment policy, and the monetary authority sets the interest rate according to a Taylor-type rule. Below we present the framework in more detail.

3.1 Epidemic Model: A-SIR

We modify the classic SIR model along two dimensions. First, following Eichenbaum, Rebelo, and Trabandt (2020b), we make probabilities of being infected depend on economic activity. Second, following Prem et al. (2020), infected people are either symptomatic and asymptomatic. The asymptomatic infected are less infectious than the symptomatic infected. Our baseline model abstracts away from the invention of vaccines against the coronavirus. Hence, it can be thought of as describing the COVID-19 pandemic during its early phase, i.e., before the vaccines became widely available. However, we also check the robustness of our findings to an alternative assumption about the introduction of vaccinations.

There are five types of individuals in the economy: susceptible S_t, infected asymptomatic A_t, infected symptomatic I_t, formerly asymptomatic recovered V_t, and formerly symptomatic recovered R_t. Since infected asymptomatic individuals have no infection symptoms, they behave the same as susceptible individuals, as do formerly asymptomatic infected. Before the pandemic, all agents are assumed to be identical. Once the virus starts spreading, agents become heterogeneous in whether, when, and how they contract the disease, which has consequences for their economic decisions.

There are three channels through which infection spreads. First, susceptible can be infected while consuming, with the probability of infection depending on their individual consumption level c_t^S, aggregate consumption of symptomatic infected $I_t c_t^I$, and aggregate consumption of asymptomatic infected $A_t c_t^A$. Since there is evidence that asymptomatic infected are less infectious than symptomatic, we introduce a parameter $0 \leq \kappa < 1$ to account for that. We also allow for possible isolation of symptomatic infected individuals by scaling their infectiousness with parameter $0 \leq \zeta \leq 1$. Second, susceptible agents can be infected while working with the probability of infection, depending on their individual hours worked n_t^S, and aggregate hours worked by asymptomatic infected $A_t n_t^A$. We assume that symptomatic infected either do not work or work remotely, so they do not transmit the disease via the labor channel. Finally, the infection can spread through other channels (like kindergartens, schools, family meetings, etc.), with the probability depending on the number of infected people, both symptomatic and asymptomatic, and on variable ϖ_t, which depends on the lockdown measures in place. Summing up, susceptible individual i can become infected (with symptoms or not) with probability $\varpi_{I,t}(i)$ that is given by the following formula:

$$\varpi_{I,t}(i) = \varpi_c c_t^S(i)(\zeta I_t c_t^I + \kappa A_t c_t^A) + \varpi_n n_t^S(i) \kappa A_t n_t^A + \varpi_t (I_t + \kappa A_t), \tag{1}$$

where $\varpi_c, \varpi_n > 0$ are constants controlling the relative importance of consumption and labor channels in transmitting the virus.[1]

Since asymptomatic infected individuals experience no symptoms, they do not realize that they are infected. Therefore, while making their decisions, susceptible, asymptomatic infected, and formerly asymptomatic recovered behave the same. We call this group supposedly susceptible and their mass is $\tilde{S}_t = S_t + A_t + V_t$. Each group member could be susceptible, asymptomatic infected, or formerly asymptomatic recovered, and knows the probabilities of belonging to each category. The evolution of susceptible individuals is given by the following equation:

$$S_{t+1} = (1 - \varpi_{I,t}) S_t. \tag{2}$$

[1]Obviously, ϖ_c, ϖ_n, and ϖ_t must be such that $0 \leq \varpi_{I,t} \leq 1$ at every time t. We check in all our simulations that this is indeed the case.

When an individual becomes infected, he or she is symptomatic with probability ρ and asymptomatic with probability $1-\rho$. Infected asymptomatic recover with probability ϖ_R. Infected symptomatic die with probability $\varpi_{D,t}$ and recover with probability $\varpi_R - \varpi_{D,t}$. The evolution of symptomatic infected, asymptomatic infected, formerly asymptomatic infected, and recovered agents is then given by the following equations:

$$I_{t+1} = (1 - \varpi_R)I_t + \rho\varpi_{I,t}S_t \tag{3}$$

$$A_{t+1} = (1 - \varpi_R)A_t + (1 - \rho)\varpi_{I,t}S_t \tag{4}$$

$$V_{t+1} = V_t + \varpi_R A_t \tag{5}$$

$$R_{t+1} = R_t + (\varpi_R - \varpi_{D,t})I_t. \tag{6}$$

Finally, the number of deceased D_t evolves according to

$$D_{t+1} = D_t + \varpi_{D,t}I_t. \tag{7}$$

3.2 Supposedly Susceptible Individuals

As we mentioned above, this group consists of susceptible, asymptomatic infected, and formerly asymptomatic recovered individuals. The probability that a supposedly susceptible agent i becomes symptomatic infected $\tilde{\varpi}_{I,t}(i)$ equals

$$\tilde{\varpi}_{I,t}(i) = \rho\varpi_{I,t}(i)\frac{S_t}{\tilde{S}_t}. \tag{8}$$

Each period, agents choose consumption $\tilde{c}_t(i)$, labor supply $\tilde{n}_t(i)$, and nominal bond holdings $\tilde{B}_{t+1}(i)$ that pay a nominal interest rate $\mathcal{I}_t$. Their expenditure is financed with labor income that earns a nominal wage W_t, bond holdings from the previous period $\tilde{B}_t(i)$, and lump-sum real transfers from the government Γ_t. For simplicity, we assume that profits from the firms are also collected by the government and transferred to households as a part of Γ_t. Supposedly susceptible agents face the following budget constraint:

$$(1 + \tau_{c,t})P_t\tilde{c}_t(i) + \tilde{B}_{t+1}(i) = (1 - \tau_{n,t})W_t\tilde{n}_t(i) + \mathcal{I}_{t-1}\tilde{B}_t(i) + P_t\Gamma_t, \tag{9}$$

where $\tau_{c,t}$ denotes the consumption tax rate and $\tau_{n,t}$ the labor income tax rate. We use these taxes to model administrative restrictions on economic activity (lockdowns).

The recursive problem of the supposedly susceptible household is given by

$$\tilde{U}_t(\tilde{b}_t(i)) = \max_{\tilde{c}_t(i),\tilde{n}_t(i),\tilde{B}_{t+1}(i),\tilde{\varpi}_{I,t}(i)} \log \tilde{c}_t(i) + \theta \log(1 - \tilde{n}_t(i)) + \beta(1 - \tilde{\varpi}_{I,t}(i))\tilde{U}_{t+1}(\tilde{b}_{t+1}(i)) + \beta\tilde{\varpi}_{I,t}(i)U_{I,t+1}(\tilde{b}_{t+1}(i)) \quad (10)$$

subject to the probability of becoming infected (8) and the budget constraint (9), where $\tilde{b}_t = \tilde{B}_t/P_{t-1}$ denotes real bond holdings.

The aforementioned problem results in the following first-order conditions:

$$\frac{1}{\tilde{c}_t} = \tilde{\lambda}_{S,t}(1 + \tau_{c,t}) - \tilde{\lambda}_{\varpi,t}\rho\frac{S_t}{\tilde{S}_t}\varpi_c(\zeta I_t c_t^I + \kappa A_t \tilde{c}_t) \quad (11)$$

$$\frac{\theta}{1 - \tilde{n}_t} = \tilde{\lambda}_{S,t}(1 - \tau_{n,t})w_t + \tilde{\lambda}_{\varpi,t}\rho\frac{S_t}{\tilde{S}_t}\varpi_n \kappa A_t \tilde{n}_t \quad (12)$$

$$\tilde{\lambda}_{\varpi,t} = \beta[U_{I,t+1}(\tilde{b}_{t+1}) - \tilde{U}_{t+1}(\tilde{b}_{t+1})] \quad (13)$$

$$\tilde{\lambda}_{S,t} = \beta[(1 - \tilde{\varpi}_{I,t})\tilde{\lambda}_{S,t+1} + \tilde{\varpi}_{I,t}\lambda_{I,t+1}]\frac{\mathcal{I}_t}{\pi_{t+1}}, \quad (14)$$

where $\tilde{\lambda}_{\varpi,t}$ and $\tilde{\lambda}_{S,t}/P_t$ are the Lagrangian multipliers on (8) and (9), respectively, $\lambda_{I,t}/P_t$ is the Lagrange multiplier on the budget constraint of symptomatically infected agents that we define in Equation (15) below, $w_t = W_t/P_t$ is the real wage, and we have omitted individual indices i for better clarity. The first two conditions show that supposedly susceptible individuals, while deciding how much to consume and work, take into account the risk of becoming infected during these activities. The pandemic hence endogenously limits their labor supply and consumption. The last term of the first two equations denotes the loss of utility due to infection multiplied by the risk of getting infected during the respective activity. The third equation stipulates that the Lagrangian multiplier $\tilde{\lambda}_{\varpi,t}$ equals the discounted utility loss due to infection. The fourth equation is the Euler equation.

3.3 Symptomatic Infected Individuals

We assume that, to a certain degree, infected individuals can work remotely, but their productivity is lowered by factor $0 \leq \xi \leq 1$. They choose consumption $c_t^I(i)$, labor supply $n_t^I(i)$, and bond holdings $B_{t+1}^I(i)$. Their return on bond holding equals $\mathcal{I}_t/(1-\varpi_{D,t})$ to account for the fact that a fraction $\varpi_{D,t}$ of infected dies each period. Their budget constraint is as follows:

$$(1+\tau_{c,t})P_t c_t^I(i) + B_{t+1}^I(i) = W_t \xi n_t^I(i) + \mathcal{I}_{t-1} B_t^I(i)/(1-\varpi_{D,t-1}) + P_t \Gamma_t. \tag{15}$$

The recursive problem of the infected household is given by

$$\begin{aligned} U_t^I(b_t^I(i)) = \max_{c_t^I(i), n_t^I(i), B_{t+1}^I(i)} & \log c_t^I(i) + \theta \log(1-n_t^I(i)) \\ & + \beta(1-\varpi_R) U_{t+1}^I(b_{t+1}^I(i)) \\ & + \beta(\varpi_R - \varpi_{D,t}) U_{t+1}^R(b_{t+1}^I(i)) + \beta \varpi_{D,t} U^D \end{aligned} \tag{16}$$

subject to the budget constraint (15), and where U_D denotes disutility associated with dying. Omitting individual indices, the first-order optimality conditions can be written as

$$\frac{1}{c_t^I} = \lambda_{I,t}(1+\tau_{c,t}) \tag{17}$$

$$\frac{\theta}{1-n_{I,t}} = \xi \lambda_{I,t} w_t \tag{18}$$

$$\lambda_{I,t} = \beta[(1-\varpi_R)\lambda_{I,t+1} + (\varpi_R - \varpi_{D,t})\lambda_{R,t+1}] \frac{\mathcal{I}_t}{\pi_{t+1}(1-\varpi_{D,t})}, \tag{19}$$

where $\lambda_{R,t}/P_t$ is the Lagrange multiplier on the budget constraint of symptomatic recovered agents defined in Equation (20) below.

3.4 Symptomatic Recovered Individuals

The recovered individuals are not at risk of getting infected, so they are not afraid of it anymore. Their problem is exactly as if there was no epidemic. They choose consumption $c_t^R(i)$, labor supply $n_t^R(i)$, and bond holdings $B_{t+1}(i)$. Their budget constraint is as follows:

$$(1+\tau_{c,t})P_t c_t^R(i) + B_{t+1}^R(i) = (1-\tau_{n,t})W_t n_t^R(i) + \mathcal{I}_{t-1}B_t^R(i) + P_t\Gamma_t. \quad (20)$$

The recursive problem of the recovered household is given by

$$U_t^R(b_t^R(i)) = \max_{c_t^R(i),n_t^R(i),B_{t+1}^R(i)} \log c_t^R(i) + \theta\log(1-n_t^R(i)) + \beta U_{t+1}^R(b_{t+1}^R(i)) \quad (21)$$

subject to the budget constraint (20). Standard first-order conditions follow.

3.5 Firms

Retail firms maximize profit in a perfectly competitive framework. They buy intermediate goods $y_t(\iota)$ at price $P_t(\iota)$ from their producers indexed by ι and combine them into final goods y_t, which they sell to households at a price P_t. They maximize the following profits:

$$P_t y_t - \int_{\iota\in[0,1]} P_t(\iota)y_t(\iota)d\iota \quad (22)$$

subject to the technological constraint

$$y_t = [\int_{\iota\in[0,1]} y_t(\iota)^{\frac{\varepsilon-1}{\varepsilon}}d\iota]^{\frac{\varepsilon}{\varepsilon-1}}. \quad (23)$$

Solving this problem, we get the following equation describing the demand for intermediate goods:

$$y_t(\iota) = \left(\frac{P_t(\iota)}{P_t}\right)^{-\varepsilon} y_t, \quad (24)$$

and from the zero-profit condition follows the formula for the aggregate price level,

$$P_t = [\int_{\iota\in[0,1]} P_t(\iota)^{1-\varepsilon}d\iota]^{\frac{1}{1-\varepsilon}}. \quad (25)$$

We assume that each intermediate good firm ι operating in a monopolistically competitive environment produces its product $y_t(\iota)$ with the following technology:

$$y_t(\iota) = Zn_t(\iota), \tag{26}$$

where $n_t(\iota)$ denotes labor demand by firm ι and $Z > 0$ is the level of productivity. Since the total cost is $w_t n_t(\iota)$, production function (26) implies the following expression for the marginal cost:

$$mc_t = \frac{w_t}{Z}, \tag{27}$$

which is the same for all firms.

Each period, an intermediate good firm receives a signal to adjust prices with probability $1-\delta$ and resets the price to $\tilde{P}_t(\iota)$ to maximize the sum of discounted profits

$$\max_{\tilde{P}_t(\iota), \{y_{t+j}(\iota)\}_{j=0}^{\infty}} E_t \sum_{j=0}^{\infty} (\beta\delta)^j \Lambda_{t,t+j} \left(\frac{\tilde{P}_t(\iota)}{P_{t+j}} - mc_{t+j} \right) y_{t+j}(\iota) \tag{28}$$

subject to demand function (24). Absent the signal, the price remains unchanged, $P_{t+1}(\iota) = P_t(\iota)$. The discount factor $\Lambda_{t,t+j}$ is computed as a weighted average of marginal utility of consumption across all types of households.

3.6 Government, Central Bank, and the Health-Care System

The government uses the consumption and labor tax rates $\tau_{c,t}$ and $\tau_{n,t}$ to restrict market activity and slow down the spread of the virus. Since the collected revenue is rebated to households, these taxes discourage agents from consuming and working, but do not directly affect their average income. Additionally, the government transfers firms' profits to households. As our model describes a one-sector economy, the fiscal authority does not supply rescue packages to industries and workers that are hit most, as was the case in many countries during the COVID-19 pandemic. Hence, we implicitly assume that appropriate income redistribution is in place and that it is financed without creating market distortions (e.g., with lump-sum taxes). Thus, we abstract from income inequality and focus on the aggregate demand management mandate of central banks. The budget of the government can then be assumed to be balanced every period, leading to the following constraint:

$$\tau_{c,t} P_t c_t + \tau_{n,t} W_t n_t + P_t y_t - W_t n_t = (\tilde{S}_t + I_t + R_t)\Gamma_t, \tag{29}$$

where aggregate consumption c_t and labor n_t will be defined below.

We assume a simple but operational rule for lockdown policies, which relates the tax rates to the number of infected agents,

$$\tau_{c,t} = \Phi_c I_t \tag{30}$$

$$\tau_{n,t} = \Phi_n I_t, \tag{31}$$

where $\Phi_c, \Phi_n > 0$. Additionally, we assume that the lockdown policy affects transmission via the third channel,

$$\omega_t = \omega(1 - \tau_{c,t})^{\Phi_\omega}, \tag{32}$$

where $\omega, \Phi_\omega > 0$. This reflects the observation that consumption lockdowns (closures of shops or ski lifts) were usually introduced simultaneously with non-economic restrictions (e.g., closures of schools).

We assume that the central bank conducts monetary policy according to a Taylor-type rule that responds to the deviation of inflation from the steady state, responds to the output gap, and possibly allows for reaction to the number of infected agents

$$\frac{\mathcal{I}_t}{\bar{\mathcal{I}}} = \left(\frac{\pi_t}{\bar{\pi}}\right)^{\Phi_\pi} \left(\frac{y_t}{y_t^f}\right)^{\Phi_y} \exp(I_t)^{\Phi_I}, \tag{33}$$

where $\Phi_\pi, \Phi_y, \Phi_I \geq 0$ and y_t^f denotes the flexible-price level of output.

Following the epidemic literature, we assume that the probability of dying depends on the strain put by the pandemic on the heath-care system. We assume a piecewise linear relationship to reflect the notion that the probability increases in the number of infected, but levels off beyond a certain point,

$$\varpi_{D,t} = \min\left[\left(1 + \frac{I_t}{\nu_0}\right)\varpi_D, \nu_1 \varpi_D\right], \tag{34}$$

where $\nu_0, \nu_1 > 0$.

3.7 Market Clearing

At the beginning of the epidemic, there is measure one of agents. We denote the set of agents that are supposedly susceptible at time t as $\mathbb{S}_t$, symptomatically infected as $\mathbb{I}_t$, and symptomatically recovered as $\mathbb{R}_t$. Then the final good market clearing can be written as

$$\int_{i\in\mathbb{S}_t} \tilde{c}_t(i)di + \int_{i\in\mathbb{I}_t} c_t^I(i)di + \int_{i\in\mathbb{R}_t} c_t^R(i)di \equiv c_t = y_t. \tag{35}$$

The labor market clearing condition has the following form:

$$\int_{i\in\mathbb{S}_t} \tilde{n}_t(i)di + \int_{i\in\mathbb{I}_t} n_t^I(i)di + \int_{i\in\mathbb{R}_t} n_t^R(i)di \equiv n_t = \int_{\iota\in[0,1]} n_t(\iota)d\iota. \tag{36}$$

Substituting from (26) and (24), we get the aggregate production function,

$$\Delta_t y_t = z_t n_t, \tag{37}$$

where price dispersion Δ_t is given by

$$\Delta_t = \int_{\iota\in[0,1]} \left(\frac{P_t(\iota)}{P_t}\right)^{-\varepsilon} d\iota. \tag{38}$$

Finally, assets by agent type evolve according to

$$\begin{aligned} \tilde{S}_{t+1}\tilde{B}_{t+1} &= (1-\tilde{\varpi}_{I,t}) \int_{i\in\mathbb{S}_t} \tilde{B}_{t+1}(i)di \\ I_{t+1}B_{t+1}^I &= (1-\varpi_R) \int_{i\in\mathbb{I}_t} B_{t+1}^I(i)di + \tilde{\varpi}_{I,t} \int_{i\in\mathbb{S}_t} \tilde{B}_{t+1}(i)di \\ R_{t+1}B_{t+1}^R &= \int_{i\in\mathbb{R}_t} B_{t+1}^R(i)di + (\varpi_R - \varpi_{D,t}) \int_{i\in\mathbb{I}_t} B_{t+1}^I(i)di \end{aligned} \tag{39}$$

and bond market clearing requires

$$\tilde{S}_t\tilde{B}_t + I_t B_t^I + R_t B_t^R = 0. \tag{40}$$

4. Calibration

Our model embeds the pandemic block into an otherwise fairly standard quantitative business cycle setup. To calibrate the former, we draw on the epidemiological literature and particularly on the most recent papers dealing directly with the COVID-19 disease. The parameterization of the macroeconomic block is based on the vast DSGE literature. A complete list of parameter values is given in Table 1.

We start with the pandemic block. To calibrate the parameters controlling the spread of disease via consumption, labor, and other activities, we follow Eichenbaum, Rebelo, and Trabandt (2020c) and set them such that, absent containment measures, each of the two economic channels accounts for one-sixth of the transmission and about two-thirds of the population become infected before the pandemic dies out. The targeted relative role of transmission channels is based on evidence on the influenza pandemic described by Ferguson et al. (2006), combined with information from the Bureau of Labor Statistic's Time Use Survey. The terminal share of the population that either recovers or dies is consistent with the estimated herd immunity levels of 60–70 percent, as implied by standard models; see, e.g., Gomes et al. (2020) or Prem et al. (2020).

As in Atkeson (2020), we assume that it takes 18 days (i.e., 7/18 periods in our weekly model) to either recover or die from the disease, which is also consistent with more recent estimates reported by Zhou et al. (2020). This, together with the infection fatality rate of 0.6 percent suggested by cross-country and meta-studies (Ioannidis 2020; O'Driscoll et al. 2020), brings us to our calibrated value of basic death probability. The share of symptomatic agents in all infected is calibrated at 0.6, reflecting a compromise between a wide range of estimates reported in the COVID-19 medical literature (Oran and Topol 2020; Wells et al. 2020; Yanes-Lane et al. 2020). The relative infectiousness of asymptomatically infected is also subject to high uncertainty, so we use the value of 0.5, consistent with a meta-study by Byambasuren et al. (2020), corrected upwards by recent evidence from Bi et al. (2020). The relative productivity of infected agents is set to 0.8. Following Ferguson et al. (2020) and Wilde et al. (2021), we assume that mortality doubles when the number of infected exceeds 1 percent of the population. Parameters of

Table 1. Baseline Parameters Values

Parameter	**Value**	**Description**
A. Epidemics Block		
ϖ_c	0.212	Parameter Governing Infection through Consumption Activity
ϖ_n	1.185	Parameter Governing Infection through Labor Activity
ϖ	0.570	Parameter Governing Infection through Other Activity
ϖ_R	0.389	Probability of Becoming Removed (Either Death or Recovery)
ϖ_D	$7/18 \cdot 0.006$	Basic Probability of Dying
ρ	0.6	Probability of Being Symptomatic Conditional on Infection
κ	0.5	Infectiousness of Asymptomatic Relative to Symptomatic
ζ	1	Non-isolation of Infected
ξ	0.8	Relative Productivity of Infected Households
U_d	–3,863	Disutility of Death
ν_0	0.01	Parameter Governing Capacity Constraint on Health-Care System
ν_1	3	Parameter Governing Capacity Constraint on Health-Care System
B. Households		
β	$0.99^{1/13}$	Discount Factor
θ	1.447	Weight on Labor in Utility
C. Firms		
Z	2	Productivity
ε	6	Elasticity of Substitution between Product Varieties
δ	$0.75^{1/13}$	Calvo Probability
D. Policy		
Φ_π	1.5	Interest Rate Reaction to Inflation
Φ_y	0.5/52	Interest Rate Reaction to Output Gap
Φ_I	0	Interest Rate Reaction to Infected
Φ_c	7.65	Consumption Channel Lockdown
Φ_n	3.8	Work Channel Lockdown
Φ_ω	3.8	Elasticity of Other Activities Channel to Lockdown

function (34) are set to extrapolate these assumptions, simultaneously setting a maximum mortality rate of $3 \cdot \varpi_D$.

The parameters related to the macroeconomic part of the model are standard for the business cycle literature. We use well-established values, converting them to weekly frequency wherever appropriate. Our calibration of the discount factor is based on its standard value of 0.99 used in quarterly models. The weight on leisure in utility targets 40 percent of time spent at work-related activities. The elasticity of substitution between intermediate inputs is set to obtain the product markup of 20 percent. The degree of price stickiness is chosen by expressing the standard value of quarterly Calvo probability of 0.75 in weekly units. The parameters describing the interest rate feedback to inflation and the output gap in the monetary policy reaction function are set to 1.5 and 0.5 (converted to weekly), respectively, as postulated by the standard Taylor rule.

Finally, we set the disutility associated with dying and the three parameters related to lockdowns (U_D, Φ_c, Φ_n, and Φ_ω). We proceed as follows. First, we calculate the fallout of GDP in Sweden, a country where relatively weak administrative containment measures have been applied. Keeping $\Phi_c = \Phi_n = 0$, we set the disutility of dying such that the model implied recession matches the one in the data. In other words, we assume that the recession in Sweden was driven by private-sector decisions (which clearly depend on the fear of dying). Then we move to calibrate the lockdown parameters. To this end we calculate lost output, the change in inflation, and the death rate in the euro area. Then Φ_c, Φ_n, and Φ_ω are set jointly to match these values given the disutility of death calculated earlier.[2]

[2] Both in Sweden and in the euro area, we calculate the average difference between output in the period 2020:Q1–2021:Q1 and an extrapolated trend of real GDP growth (calculated over the previous 20 years). For Sweden the fallout is 3.4 percent and for the euro area 6.5 percent. To calculate the change in the inflation rate in the euro area, we subtract average inflation in the period 2020:Q1–2021:Q1 from average inflation in 2019 (inflation declines by 0.78 percent). The death rate is calculated as the ratio of excess deaths to total population and amounts to approximately 0.23 percent (Institute for Health Metrics and Evaluation 2021).

5. Simulation Results

We are now ready to use our model to analyze the macroeconomics effects of the COVID-19 pandemic. We proceed as follows. First, we study the interplay between epidemic and economic developments and how various health-care policies (lockdowns, isolation of infected, etc.) affect the outcomes. Then we discuss the role of monetary policy, focusing both on normative and positive aspects. Our solution method relies on deterministic simulations that take into account the whole nonlinear structure of the model. Since our preferences are homothetic, we can aggregate behavior within each group. Moreover, we use a linear Taylor expansion to evaluate value functions at arguments off the equilibrium paths. The resulting equilibrium conditions expressed in terms of aggregates are listed in the online appendix (available at http://www.ijcb.org).

5.1 The Epidemic and Containment Measures

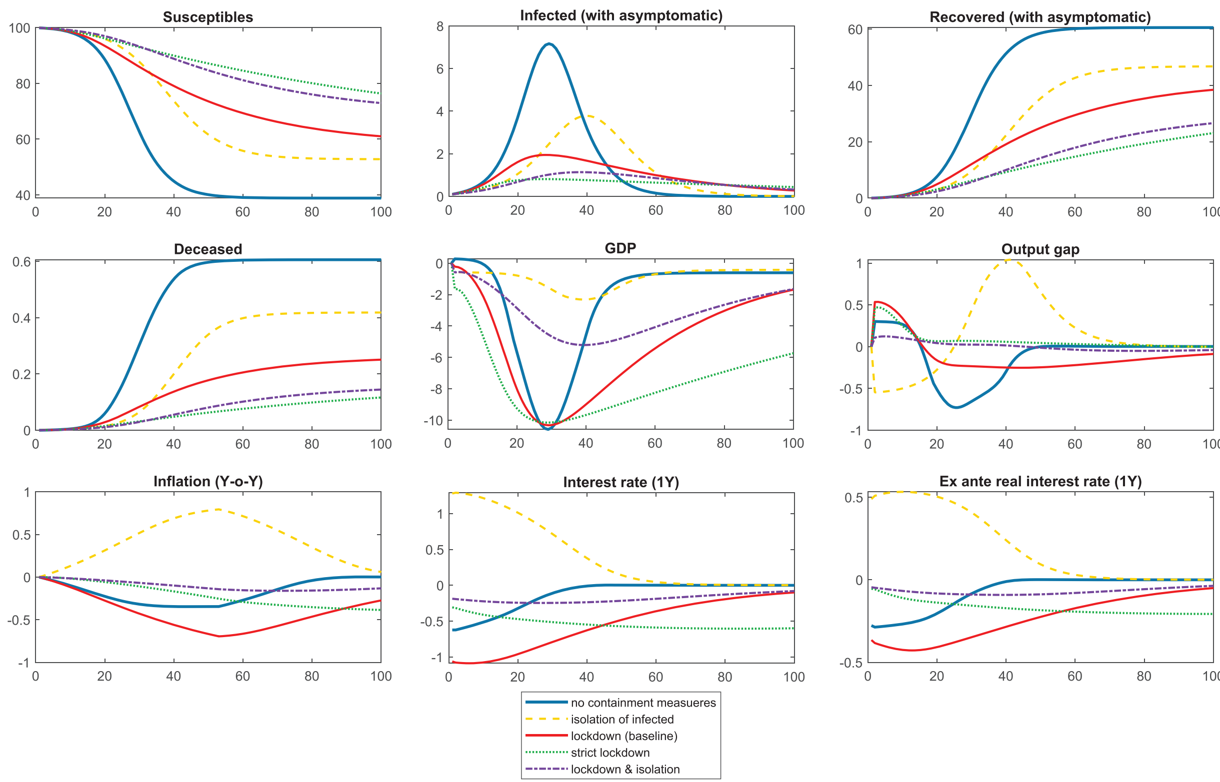
We start by constructing and feeding into our model several stylized scenarios based on different assumptions about containment measures introduced by the authorities. The scenarios are not intended to provide a precise reflection of the measures or developments in any particular country. Our goal is instead to encompass the wide range of approaches adopted across the world.[3] These scenarios help us explain how our model works and, in particular, how it manages the interplay between the epidemic and economic developments. They will also serve us as benchmarks upon which we will later test various monetary policy strategies.

A useful starting point is a laissez-faire or no-containment-measures scenario, under which the authorities do not impose any containment measures on the economy, i.e., $\Phi_c = \Phi_n = 0$ (solid thick blue line in Figure 1).[4] We calibrated it to match the decline of GDP

[3]While dealing with the pandemic, various countries adopted a wide range of different policies. On the one extreme, Sweden relied for some time on voluntary recommendations. On the other, several countries, e.g., Vietnam, Malaysia, Thailand, Australia, and New Zealand, implemented zero COVID policies. However, most countries adopted strategies that can be placed between these two approaches, introducing mandatory lockdowns that differed in severity.

[4]For figures in color, see the online version of the paper at http://www.ijcb.org.

Figure 1. Epidemic Containment Policies



Note: Horizontal axis in weeks, vertical in percent.

observed in Sweden. The only administrative restrictions consist of subjecting visibly infected agents to sick leave. However, in contrast to usual sick leave procedures, but in line with the COVID pandemic practice, we assume that agents can work from home, albeit with lower productivity, as described in Section 4. As the epidemic develops and the number of infected agents increases, the economy starts to contract. This happens for several reasons. First, as described above, infected agents are assumed less productive, so income falls. More importantly, however, a large fraction of the remaining society are aware that the risk of getting infected via work and consumption channels increases. This applies not only to susceptible agents but also to asymptomatically infected and asymptomatically recovered, as they do not know that they cannot fall ill anymore. These groups limit their consumption and work effort, and, as they are much more populous than infected, this is the main reason behind the contraction. Over the first year of the pandemic, output declines by approximately 4.1 percent and inflation by 0.3 percent. Total, final fatalities amount to approximately 0.61 percent of the population.

5.1.1 Output and Fatalities

Let us now move to the scenarios that assume some health-care policy intervention. It should be explained upfront that these policies are generally successful in limiting the fatality rate since they allow to flatten the infection curve and limit the strain on the health-care system. Furthermore, the considered containment measures have also the potential to improve welfare. This is because agents do not fully internalize the cost of the epidemic. In particular, infected agents do not take into account that their individual consumption and work activities affect the spread of the disease. This externality has been described in the epidemic and economic literature, so we limit ourselves to a brief mentioning (e.g., Eichenbaum, Rebelo, and Trabandt 2020b).

Our baseline policy scenario is our calibrated lockdown, and we present it with the solid thin red line in Figure 1. We designed it to match the experience of the euro-area countries. Under this scenario, the authorities impose administrative measures discouraging economic activity. As discussed in Section 4, we implement this policy using taxes on consumption and labor income, which are assumed to respond to the evolution in the number of visibly infected. The lockdown is much more costly for the economy than the laissez-faire variant discussed above, as output declines on average by 6.7 percent during the first year. However, not surprisingly, limiting contacts in the population reduces the number of fatalities sharply. Ultimately, the death ratio amounts to slightly less than 0.26 percent of the population. These results are in line with empirical evidence on the impact of lockdown on economic activity and the spread of the virus (including, among others, Alfano and Ercolano 2020; Mendoza et al. 2020; Castex, Dechter, and Lorca 2021).

Another containment measure we consider is total isolation of the visibly infected agents, which we implement by assuming $\zeta = 0$. As a consequence, they spread the disease neither via work nor via the consumption channel. While many countries made efforts to introduce such a policy, we decided not to make it our baseline scenario. Due to practical problems with widespread testing, contact tracking, and delays between the incubation and the test result, it seems doubtful whether this policy has historically played a role similar to that implied by our model. We test two variants: one under which this is the only containment policy (dashed yellow line in Figure 1), and one when it is coupled with the economy-wide lockdown policy described above (dash-dotted purple line in Figure 1). Pure isolation is relatively uncostly, as output declines by only 1.29 percent in the first year. However, it is less successful on the epidemic front than the lockdown, as it only limits the death toll to 0.42 percent of the population. In contrast, the mix of isolation and lockdown is highly successful in containing the pandemic (fatalities amount to 0.16 percent) at a relatively small economic cost (3.39 percent output decline).

Finally, we consider a much stricter lockdown than the one introduced historically (dotted green line in Figure 1). We implement it by multiplying the baseline values of Φ_c and Φ_n by three. This scenario can be conceptually related (but has not been formally calibrated) to countries imposing zero COVID policies, like Vietnam, Malaysia, or New Zealand. The economy has been frozen for over two years, but the policy limits the ultimate death toll to slightly below 0.17 percent. Such a scenario can be considered attractive in the context of vaccine development, which we abstract from in our model, as the policy has by far the lowest death toll after six quarters, a period after which vaccinations have become relatively widespread in developed countries.

5.1.2 Inflation

An interesting feature of our simulations is the behavior of inflation. While output and hours worked always contract in response to the pandemic, inflation either declines, increases, or remains barely affected, depending on the introduced containment measures. This finding squares nicely with the empirical observation that inflation in most countries declined only moderately (despite the huge economic slump), and in some countries even increased during the pandemic.

How can the differentiated reaction of inflation be explained? The outcome depends on the relative response of consumption demand and labor supply. Both decline during the pandemic, but while the former pushes inflation down, the latter puts upward pressure on prices. The strongest deflationary effect occurs under the baseline scenario. Recall that we calibrated the model to match the declining inflation rate. However, it is interesting to note that this implied a stronger lockdown on consumption than on labor. In contrast, under the laissez-faire scenario, inflation is almost flat. This is because, if left on their own, agents reduce consumption and work effort to a similar degree, leaving the aggregate demand and supply effects roughly balanced. The strongest inflationary effect occurs when infected agents are being isolated. As isolation largely reduces the risk of becoming infected via the consumption channel (some risk remains due asymptomatic agents), supposedly susceptible households now become less afraid of consuming, which raises the inflationary pressure.

5.1.3 Welfare

We conclude this part of our analysis by calculating the model-consistent cost of the epidemic. The calculation is based on aggregate welfare as defined in Equation (10), evaluated at time 0, which is the period when the first infected agent appears. We compare welfare under the epidemic with welfare in a non-epidemic world, and express the difference in percent of steady-state consumption that a susceptible agent would be ready to forego to avoid the epidemic.

Table 2 presents the findings. The laissez-faire scenario generates the highest welfare cost. It amounts to 1.24 percent of lifetime consumption, several orders of magnitude higher than the usual estimates of business cycle fluctuation costs. This number can be reduced to various degrees by the containment policies described above. For instance, the baseline lockdown cuts the cost by more than half. The most restrictive policies, namely strict lockdown and the mix of lockdown and isolation, are even more successful: the welfare cost declines to about one-quarter of that under the laissez-faire scenario.

5.2 Monetary Policy

Let us now move to monetary policy, especially to the fundamental question of its role during the pandemic. In response to the COVID-19 crisis, central banks worldwide assumed an expansionary policy stance (Cantú et al. 2021). This manifested itself in the form of deep interest rate cuts and subsequent rounds of quantitative easing. An essential goal of these interventions was to avoid a collapse of the economic and financial system and alleviate pressure on the governments implementing huge rescue plans to prevent a wave of bankruptcies and an increase in economic inequality. Our framework is too simple to address all of these multiple motives appropriately. It does, however, allow us to capture the role of central banks as powerful institutions responsible for aggregate demand management.

What we want to highlight is that the character of the COVID-19 recession is different from standard. Falling inflation and output usually call for a monetary policy easing. However, the pandemic recession is a mixture of endogenous reactions and administrative policy measures intended to limit social and economic interactions, and hence the spread of the pandemic. From this perspective, an accommodative monetary policy stance could be counterproductive because it could accelerate the epidemic and bring about more fatalities. In particular, our goal is to evaluate the relative role of two key externalities shaping the pandemic scenario. The first one is the standard New Keynesian aggregate demand externality associated with nominal rigidities, suggesting monetary accommodation in response to a contraction in economic activity. The second externality reflects

Table 2. Cost of the Epidemic

Scenario	Baseline Monetary Policy		Standard Monetary Policy		Optimized Monetary Policy		
	Welfare Cost	**Deaths**	**Welfare Cost**	**Deaths**	Φ_I	**Welfare Cost**	**Deaths**
No Containment Measures	1.240%	0.606%	1.247%	0.610%	0.0625	1.230%	0.594%
Isolation of Infected	0.845%	0.418%	0.850%	0.420%	0.0629	0.834%	0.409%
Lockdown (Baseline)	0.555%	0.263%	0.564%	0.268%	−0.0096	0.554%	0.264%
Strict Lockdown	0.383%	0.169%	0.456%	0.171%	−0.0272	0.382%	0.169%
Lockdown and Isolation	0.333%	0.162%	0.339%	0.163%	−0.0093	0.333%	0.162%

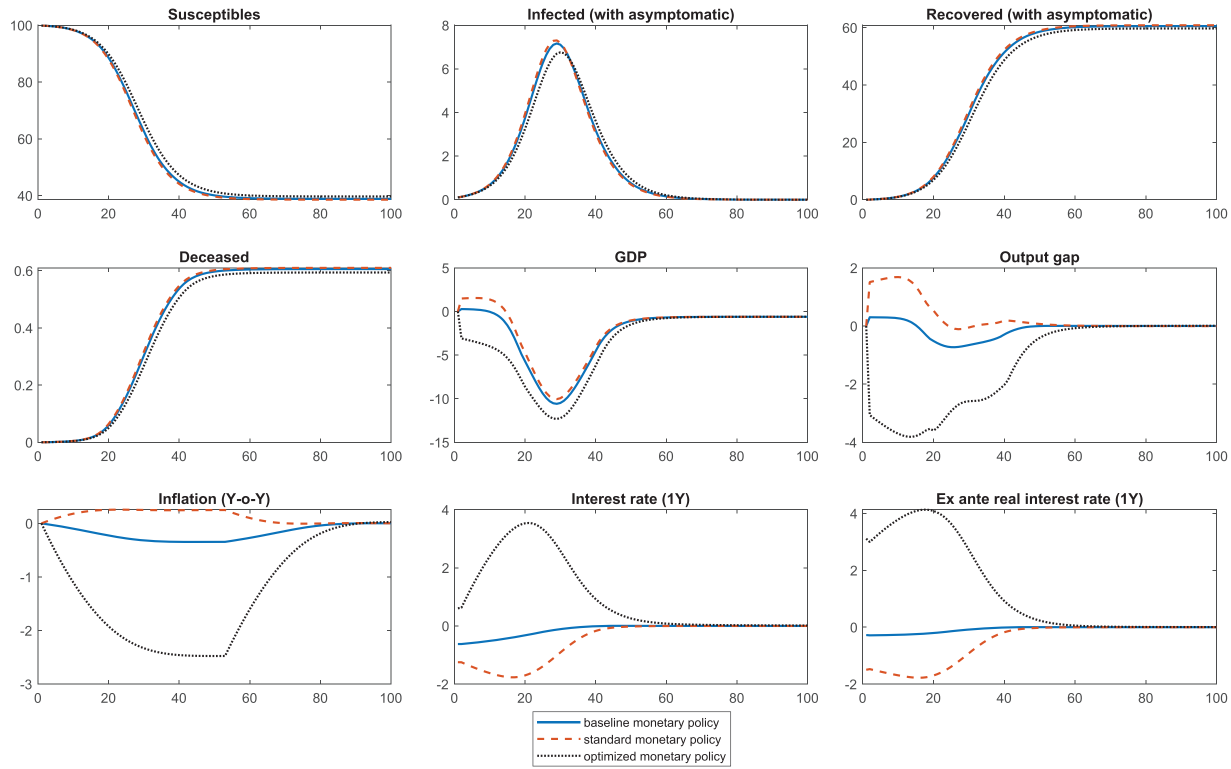
Note: The welfare cost of the epidemic is expressed in percent of lifetime consumption. Baseline monetary policy refers to the calibration presented in Table 1. Optimized monetary policy responds additionally to the number of symptomatic infected agents. Standard monetary policy responds to inflation (like baseline case) but to output deviations from trend rather than from its level under flexible prices.

agents' failure to internalize the effects of their actions on the spread of the disease. Which of these two is stronger will then be reflected in whether monetary policy should take a contractionary or expansionary stance during the pandemic.

Our policy simulations attempt to shed light on these issues. To this end, we impose on each of the scenarios described before two types of monetary policy. First, we show what would happen if the monetary authorities reacted to the deviation of output not from its flexible-price level (as we have assumed so far) but from the steady state. This alternative formulation, which we will refer to as standard monetary policy, is more common in central bank practice, as the natural (flexible-price) level output is unobservable. Second, we design monetary policy optimized for the pandemic world. To this end, we search for the monetary policy rule parameter Φ_I that maximizes the social welfare function (10). While such an approach does not produce a globally optimal policy in our model, we believe that relating the interest rate to the number of infected agents realistically captures the idea of reacting to the pandemic while keeping the rule operational.

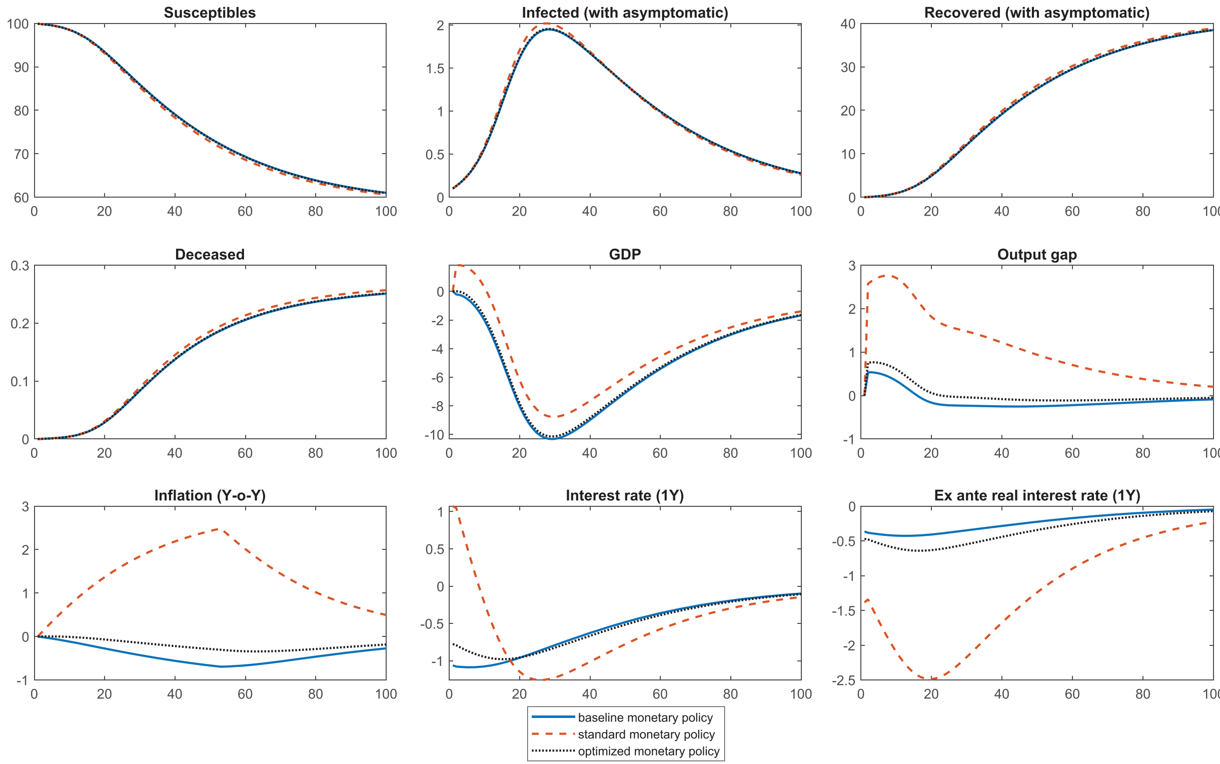
Figures 2–6 and Table 2 document our findings. Let us start with the standard monetary reaction function (dashed red line). As this rule does not take into account the strongly negative effect of the pandemic on the natural level of output, the implied monetary policy stance is clearly more expansionary than under our baseline specification relying on the flexible-price-based output gap, which under all scenarios considered is much closer to the steady state than GDP. The difference is weakest in the variant of isolation (Figure 5), as in this case the recession is relatively shallow, and strongest (at least in the first year of the pandemic) for the baseline scenario (Figure 4). The problem with applying this standard monetary reaction in times of pandemic becomes quite evident if we consider its implications for fatalities. In a sense, monetary policy partly crowds out the effort of other authorities to limit the pandemic. Due to monetary stimulus, output declines less (as a matter of fact, it even increases initially), but the number of fatalities goes up. These observations are complemented by the findings reported in Table 2, which additionally presents the welfare effects. Not only in the baseline, but also in the remaining containment policy scenarios, using the standard monetary policy reaction is detrimental for welfare. To keep

Figure 2. Baseline, Standard, and Optimized Monetary Policy—No Containment Measures Introduced



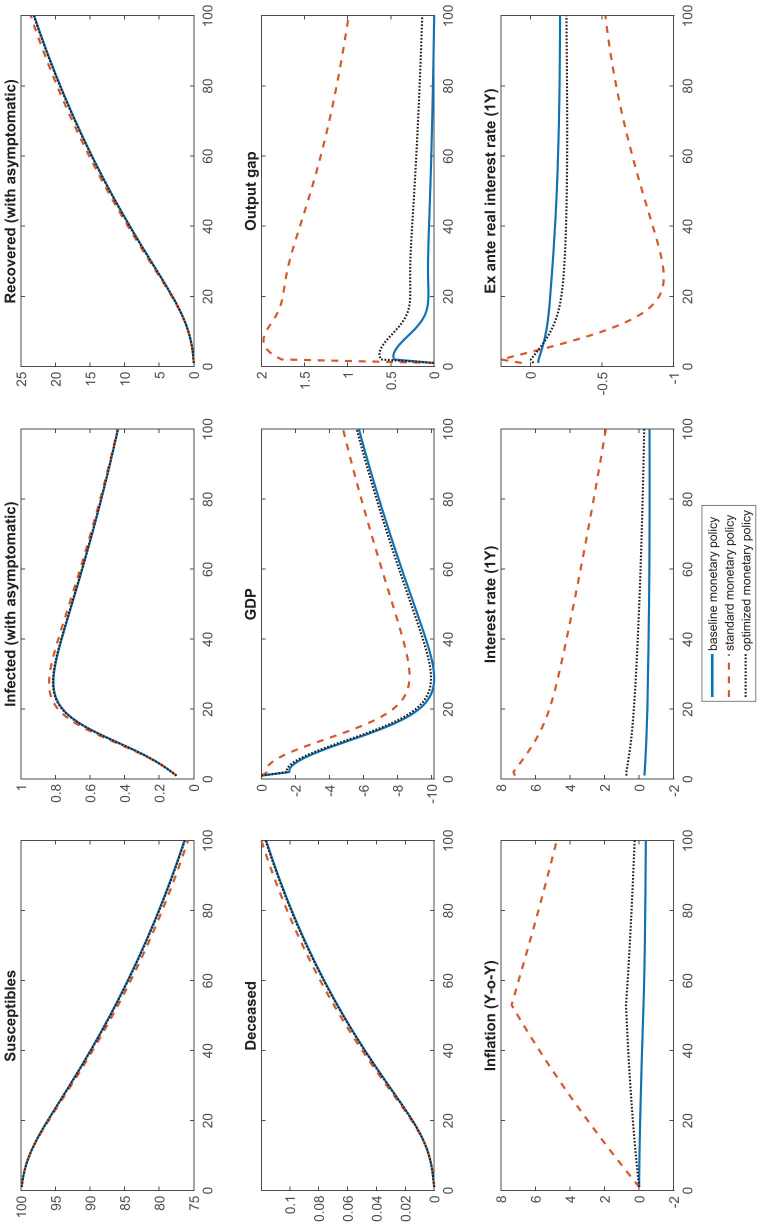
Note: Horizontal axis in weeks, vertical in percent.

Figure 3. Baseline, Standard, and Optimized Monetary Policy under Baseline Lockdown



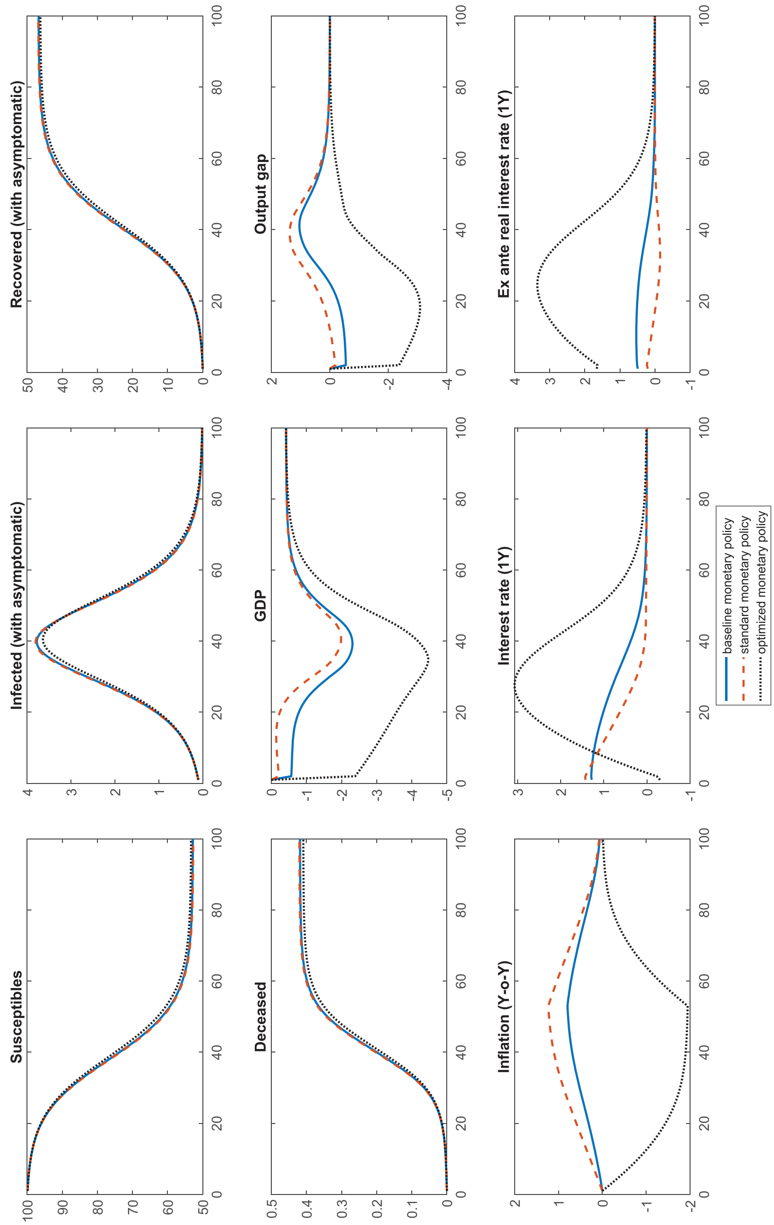
Note: Horizontal axis in weeks, vertical in percent.

Figure 4. Baseline, Standard, and Optimized Monetary Policy with Strict Lockdown



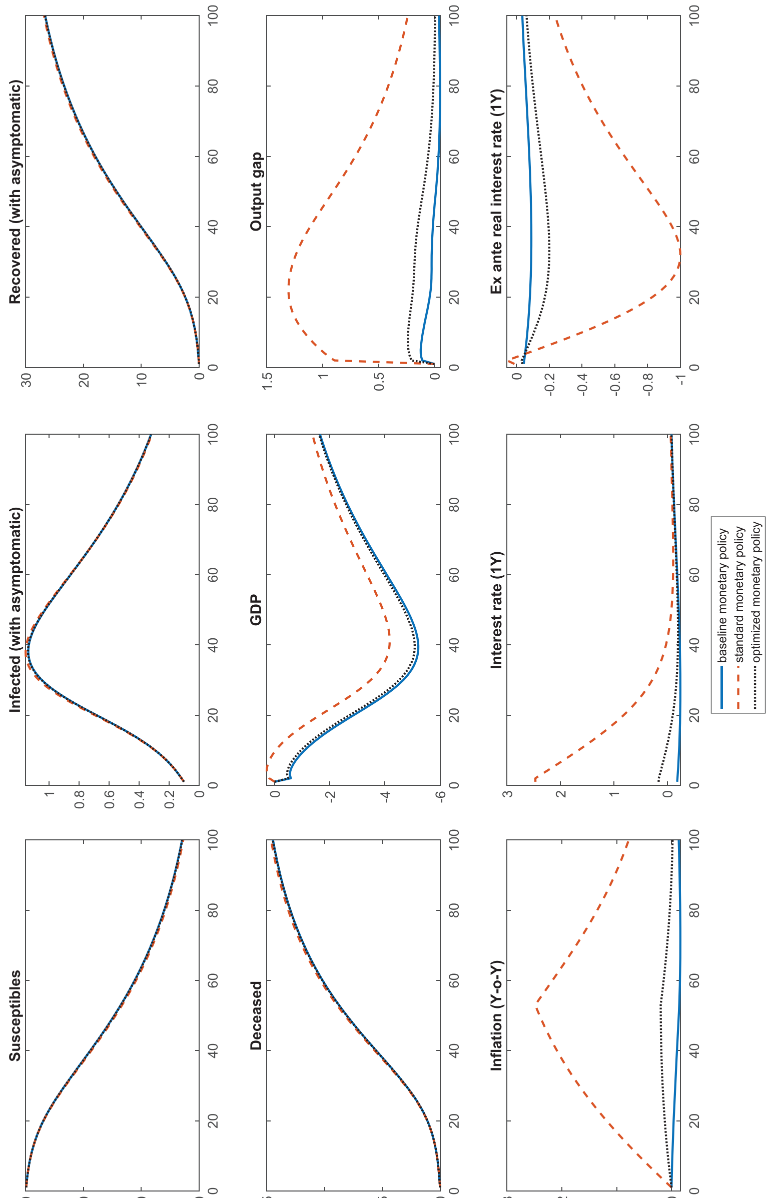
Note: Horizontal axis in weeks, vertical in percent.

Figure 5. Baseline, Standard, and Optimized Monetary Policy with Isolation



Note: Horizontal axis in weeks, vertical in percent.

Figure 6. Baseline, Standard, and Optimized Monetary Policy with Isolation and Lockdown



Note: Horizontal axis in weeks, vertical in percent.

things in proportion, it needs to be stated clearly that, in relative terms, these effects are not large, but the direction is unequivocal.

These findings raise the question of whether monetary policy can be useful at all in such exceptional circumstances as the pandemic. To provide an answer, we run our second experiment and look for an optimized reaction of interest rates to the number of visibly infected agents. The first column of the optimized policy panel in Table 2 collects the optimized reaction parameters. Clearly, they all differ from zero, which means that policy has some role to play. However, the optimized central bank behavior depends strongly on the underlying containment policy. When the containment is absent or weak (isolation), the optimized Φ_I is positive, meaning that monetary policy reaction to the pandemic should, in fact, be contractionary. Stepping out of its usual shoes, the central bank attempts to support the fight against the pandemic and its fatal consequences. The effects can be observed in Figures 2 and 5 (dotted black line). In both cases, the real interest rate is raised sharply, generating a deeper recession. The resulting decrease in economic activity limits the spread of the disease and helps lower the number of fatalities.

Things become different when a sufficiently strong containment policy is in place. Under the remaining scenarios, the optimized monetary policy turns out to be more expansionary (although to a relatively small degree) than in normal times—the coefficient on the number of infected in the monetary policy rule is negative. This is documented in Figures 3, 4, and 6, which show a deeper decline in the real interest rates under optimized policy, with positive effects for output and inflation. This means that when public authorities care sufficiently for containing the epidemic, monetary policy can focus on its standard goal, which is to reduce the externality that arises due to price stickiness. Given that this externality implies that recessions and deflation are costly, the optimized monetary policy takes an expansionary stance.

It is worth noting that all these findings also hold when we consider an extension of our model in which we allow for the introduction of vaccines against the virus. To implement this variant, we first note that, in the case of COVID-19, the main effect of the vaccines was to bring down the mortality risk. We consider the following scenario, roughly reflecting the experience of euro-area countries. The vaccines start being introduced one year after the start of the pandemic, and it takes one additional month before they begin to work, so during this initial period, the death rate in our model is still given by Equation (34). Over the next three quarters, the mortality rate is corrected by a proportionality coefficient initialized at unity and then linearly declines to 0.3, stabilizing at this level thereafter. The results are summarized in Table 3. If we compare them with the results of the no-vaccination version of the model presented in Table 2, no material differences emerge.

All in all, how monetary policy should behave during the pandemic is far from trivial due to a trade-off between stabilizing the economy and containing the epidemic, which in turn depends on the containment policies in place. In what follows, we take a closer look at this trade-off.

5.3 The Trade-Offs

Policymakers always face multiple objective dilemmas, and they should be used to resolving them. However, at least for monetary policy, the trade-off discussed here differs dramatically from the usual one. As we already stressed, if monetary policy attempts to stabilize the economy during the pandemic, it affects the number of social interactions, the number of infections, and, unfortunately, fatalities. Thus, monetary policy during the COVID-19 pandemic probably faces the nastiest trade-off ever. We now study what this trade-off looks like and how it compares with that faced by containment policies.

Figure 7 shows the efficient policy frontiers for monetary and lockdown policies. On the horizontal axis, we show the cumulative consumption loss during the first two years of the epidemic. On the vertical axis, we present the percentage of deceased agents. The solid thick blue line plots the frontier for lockdown policies, defined as the efficient combinations of coefficients Φ_c and Φ_n in equations (30) and (31), assuming that monetary policy follows the baseline Taylor rule (33) with $\Phi_I = 0$. The dash-dotted yellow and the dashed red lines plot the efficient trade-offs for monetary policy (various levels of Φ_I) under the laissez-faire and baseline lockdown scenarios, respectively.

The first thing to note is that in all cases, a trade-off exists—saving lives occurs at an economic cost of foregone consumption. However, there is a striking difference between the effectiveness of

Table 3. Cost of the Epidemic (with vaccination)

	Baseline Monetary Policy		Standard Monetary Policy		Optimized Monetary Policy		
Scenario	**Welfare Cost**	**Deaths**	**Welfare Cost**	**Deaths**	Φ_I	**Welfare Cost**	**Deaths**
No Containment Measures	1.239%	0.606%	1.247%	0.610%	0.0632	1.229%	0.593%
Isolation of Infected	0.836%	0.414%	0.841%	0.416%	0.0664	0.823%	0.403%
Lockdown (Baseline)	0.507%	0.238%	0.519%	0.245%	−0.0002	0.507%	0.238%
Strict Lockdown	0.282%	0.115%	0.352%	0.118%	−0.0264	0.281%	0.116%
Lockdown and Isolation	0.279%	0.134%	0.285%	0.135%	−0.0050	0.279%	0.134%

Note: The welfare cost of the epidemic is expressed in percent of lifetime consumption. Baseline monetary policy refers to the calibration presented in Table 1. Optimized monetary policy responds additionally to the number of symptomatic infected agents. Standard monetary policy responds to inflation (like baseline case) but to output deviations from trend rather than from its level under flexible prices.

lockdowns and monetary policy. The former has a much steeper profile, meaning that lives can be saved at a lower economic cost. The reason is relatively simple—lockdowns are assumed to reduce the transmission via all three contagion channels, including social contacts (school closures, family-meeting restrictions, etc.). In contrast, monetary policy works only by affecting transmission via consumption and work. Consequently, lockdowns are much more efficient in containing the disease.

Nevertheless, as mentioned before, even for monetary policy, a trade-off exists: a monetary expansion (contraction) raises (reduces) the number of fatalities. This is more the case when no containment measures are in place: the dashed red line is slightly steeper than the yellow dash-dotted one. It is the consequence of the higher probability of dying because of limited health-care capacity in the laissez-faire scenario.

What are the implications of the relatively flat monetary policy trade-off? Monetary policy is not a good tool to help contain the epidemic, as a meaningful reduction in fatalities would require engineering a very deep recession. However, every coin has two sides, and this is also the case here. The relatively flat trade-off, especially when other containment policies are in place, means that a monetary expansion is not very harmful. From this perspective, central banks have some freedom to support economic growth at a relatively small cost. This explains why, under some scenarios, optimized monetary policy is expansionary.

What do all these experiments tell us about monetary policy in times of pandemics? Abstracting away from fiscal or financial stability considerations, the optimal monetary policy stance depends on whether sufficient containment measures have been introduced. If this is the case, then monetary policy is free to act in its usual role of stabilizing the business cycle, providing monetary stimulus to an economy that suffers a deep recession. Otherwise, the monetary policy stance should be even contractionary, as the life-saving motive dominates. Clearly, the latter situation is a third-best option since, as we have shown, central bank instruments are better suited to steering the economy than decreasing the number of fatalities. This means that saving lives can be brought about only at a considerable economic cost.

All of this brings us to a conclusion related to the motives that we abstracted away so far. Since the health cost of a monetary expansion is relatively small, central banks are probably well suited to offer the necessary support to the fiscal authority that introduces packages helping survive those businesses that are particularly affected by the introduced lockdowns. Formalizing this conclusion would, however, require a different modeling strategy, and we leave this issue for further research.

6. Conclusions

After the outbreak of the COVID-19 pandemic, monetary policy has been eased in many countries to an unprecedented degree. However, at the same time, several economists have pointed out that in the pandemic, central banks face a new trade-off, one between stabilizing the economy and containing the epidemic. While the latter is obviously not the standard goal of central banks, they must be aware that under these very special circumstances, monetary policy actions have an impact on the epidemic and its (possibly fatal) consequences. Our paper investigates this trade-off and its implications for monetary policy. To this end, we construct a model that draws from the epidemic modeling literature and the macroeconomic business cycle literature. More precisely, we connect a SIR-type model with a standard New Keynesian framework. It allows to speak not only about the pandemic (and potential containment measures) but also about macroeconomic effects and monetary policy.

Our simulations explain the moderate reactions of inflation to the epidemic visible in the data. This happens because aggregate (consumption) demand responses are similar to aggregate (labor) supply reactions. Hence, as in the data, despite the unprecedented recession, inflation changes only slightly. Moreover, the direction of inflation reaction depends, i.a., on the containment measures applied. In our framework, containment measures are relatively efficient in containing the epidemic. In particular, lockdowns can largely reduce the spread of the disease and the number of fatalities, and substantially lower the welfare cost of the epidemic. However, their impact on inflation is relatively small and depends on the particular measures introduced.

The pandemic creates new challenges to stabilization policy. Some of them required a massive and unconventional response from central banks to prevent financial turmoil and create favorable market conditions for fiscal packages aimed at protecting the most affected industries and households. Our model abstracts from these considerations, implicitly assuming well-functioning financial markets and appropriate safety nets in place provided by the state without creating significant market distortions. Consequently, the only relevant source of economic heterogeneity among households in our model is their health history.

Under these conditions, the implications for monetary policy during the pandemic are that it should not react to a sharp deviation of output from trend as it typically does when faced with standard business cycles. Such policy reduces welfare irrespective of the underlying containment measures. The trade-off faced by the central bank is relatively flat: a decrease in the number of fatalities that can be achieved with monetary policy happens at a relatively large economic cost. This means that, not surprisingly, monetary policy is not a good tool to contain the epidemic, especially when compared with lockdowns. The flip side of this coin is that the side effects of expansionary monetary policy in the form of changes in fatalities are relatively small, so the monetary policy may have some freedom to support the economy (or the fiscal side). Nevertheless, such side effects do exist, and they are higher if containment measures are absent. As a consequence, monetary policy should be contractionary if appropriate containment measures are not in place. Conversely, if sufficiently tough measures have been introduced, monetary policy should be eased to support the economy.

References

Acemoglu, D., V. Chernozhukov, I. Werning, and M. D. Whinston. 2020. "Optimal Targeted Lockdowns in a Multi-Group SIR Model." NBER Working Paper No. 27102.

Alfano, V., and S. Ercolano. 2020. "The Efficacy of Lockdown Against COVID-19: A Cross-Country Panel Analysis." *Applied Health Economics and Health Policy* 18 (4): 509–17.

Alvarez, F. E., D. Argente, and F. Lippi. 2020. “A Simple Planning Problem for COVID-19 Lockdown.” NBER Working Paper No. 26981.

Atkeson, A. 2020. “What Will Be the Economic Impact of COVID-19 in the US? Rough Estimates of Disease Scenarios.” NBER Working Paper No. 26867.

Azzimonti, M., A. Fogli, F. Perri, and M. Ponder. 2020. “Pandemic Control in ECON-EPI Networks.” NBER Working Paper No. 27741.

Bi, Q., J. Lessler, I. Eckerle, S. A. Lauer, L. Kaiser, N. Vuilleumier, D. A. T. Cummings et al. 2020. “Household Transmission of SARS-COV-2: Insights from a Population-based Serological Survey.” medRxiv 2020.11.04.20225573.

Bodenstein, M., G. Corsetti, and L. Guerrieri. 2020. “Social Distancing and Supply Disruptions in a Pandemic.” CEPR Discussion Paper No. 14629.

Bullard, J. 2020. “Expected U.S. Macroeconomic Performance during the Pandemic Adjustment Period.” Blog Entry, “On the Economy” blog, Federal Reserve Bank of St. Louis. https://www.stlouisfed.org/on-the-economy/2020/march/bullard-expected-us-macroeconomic-performance-pandemic-adjustment-period.

Byambasuren, O., M. Cardona, K. Bell, J. Clark, M.-L. McLaws, and P. Glasziou. 2020. “Estimating the Extent of Asymptomatic COVID-19 and Its Potential for Community Transmission: Systematic Review and Meta-analysis.” *Official Journal of the Association of Medical Microbiology and Infectious Disease Canada* 5 (4): 223–34.

Cantú, C., P. Cavallino, F. De Fiore, and J. Yetman. 2021. “A Global Database on Central Banks’ Monetary Responses to COVID-19.” BIS Working Paper No. 934.

Castex, G., E. Dechter, and M. Lorca. 2021. “COVID-19: The Impact of Social Distancing Policies, Cross-country Analysis.” *Economics of Disasters and Climate Change* 5 (1): 135–59.

Clarida, R., J. Galí, and M. Gertler. 1999. “The Science of Monetary Policy: A New Keynesian Perspective.” *Journal of Economic Literature* 37 (4): 1661–1707.

Eichenbaum, M. S., S. Rebelo, and M. Trabandt. 2020a. “Epidemics in the Neoclassical and New Keynesian Models.” NBER Working Paper No. 27430.

———. 2020b. "The Macroeconomics of Epidemics." NBER Working Paper No. 26882.

———. 2020c. "The Macroeconomics of Testing and Quarantining." NBER Working Paper No. 27104.

Favero, C. A., A. Ichino, and A. Rustichini. 2020. "Restarting the Economy While Saving Lives Under COVID-19." CEPR Discussion Paper No. 14664.

Ferguson, N. M., D. A. T. Cummings, C. Fraser, J. C. Cajka, P. C. Cooley, and D. S. Burke. 2006. "Strategies for Mitigating an Influenza Pandemic." *Nature* 442 (7101): 448–52.

Ferguson, N. M., D. Laydon, G. Nedjati-Gilani, K. Ainslie, N. Imai, M. Baguelin, S. Bhatia et al. 2020. "Impact of Non-pharmaceutical Interventions (NPIs) to Reduce COVID-19 Mortality and Healthcare Demand." Working Paper, Imperial College COVID-19 Response Team.

Gertler, M., and P. Karadi. 2011. "A Model of Unconventional Monetary Policy." *Journal of Monetary Economics* 58 (1): 17–34.

Glover, A., J. Heathcote, D. Krueger, and J.-V. Rios-Rull. 2020. "Health versus Wealth: On the Distributional Effects of Controlling a Pandemic." Staff Report No. 600, Federal Reserve Bank of Minneapolis.

Gomes, M. G. M., R. Aguas, R. M. Corder, J. G. King, K. E. Langwig, C. Souto-Maior, J. Carneiro, M. U. Ferreira, and C. Penha-Goncalves. 2020. "Individual Variation in Susceptibility or Exposure to SARS-CoV-2 Lowers the Herd Immunity Threshold." medRxiv 2020.04.27.20081893.

Institute for Health Metrics and Evaluation. 2021. "Estimation of Excess Mortality Due to COVID-19." http://www.healthdata.org/specialanalysis/estimation-excess-mortality-due-covid-19-and-scalars-reported-covid-19-deaths (accessed May 15, 2021).

Ioannidis, J. 2020. "The Infection Fatality Rate of COVID-19 Inferred from Seroprevalence Data." medRxiv 2020.05.13.20101253.

Jones, C. J., T. Philippon, and V. Venkateswaran. 2020. "Optimal Mitigation Policies in a Pandemic: Social Distancing and Working from Home." NBER Working Paper No. 26984.

Kaplan, G., B. Moll, and G. L. Violante. 2020. "The Great Lockdown and the Big Stimulus: Tracing the Pandemic Possibility Frontier for the U.S." NBER Working Paper No. 27794.

Kermack, W. O., and A. G. McKendrick. 1927. “A Contribution to the Mathematical Theory of Epidemics.” *Proceedings of the Royal Society of London, Series A* 115 (772): 700–721.

Krueger, D., H. Uhlig, and T. Xie. 2021. “Macroeconomic Dynamics and Reallocation in an Epidemic: Evaluating the ‘Swedish Solution’.” ECONtribute Discussion Paper No. 075, University of Bonn and University of Cologne, Germany.

Lepetit, A., and C. Fuentes-Albero. 2021. “The Limited Power of Monetary Policy in a Pandemic.” Mimeo.

Levin, A. T., and A. Sinha. 2020. “Limitations on the Effectiveness of Monetary Policy Forward Guidance in the Context of the COVID-19 Pandemic.” NBER Working Paper No. 27748.

Mendoza, E. G., E. I. Rojas, L. L. Tesar, and J. Zhang. 2020. “A Macroeconomic Model of Healthcare Saturation, Inequality and the Output-Pandemia Tradeoff.” NBER Working Paper No. 28247.

O’Driscoll, M., G. Ribeiro Dos Santos, L. Wang, D. A. T. Cummings, A. S. Azman, J. Paireau, A. Fontanet, S. Cauchemez, and H. Salje. 2020. “Age-Specific Mortality and Immunity Patterns of SARSCoV-2.” *Nature* 590 (7844): 1–6.

Oran, D. P., and E. J. Topol. 2020. “Prevalence of Asymptomatic SARSCoV-2 Infection: A Narrative Review.” *Annals of Internal Medicine* 173 (5): 362–67.

Prem, K., Y. Liu, T. W. Russell, A. J. Kucharski, R. M. Eggo, N. Davies, S. Flasche et al. 2020. “The Effect of Control Strategies to Reduce Social Mixing on Outcomes of the COVID-19 Epidemic in Wuhan, China: A Modelling Study.” *The Lancet Public Health* 5 (5): e261–e270.

Vásconez, V. A., O. Damette, and D. W. Shanafelt. 2021. “Macroepidemics and Unconventional Monetary Policy: Coupling Macroeconomics and Epidemiology in a Financial DSGE-SIR Framework.” Working Paper No. 2021-04, Bureau d’Economie Théorique et Appliquée, UDS, Strasbourg.

Wells, P. M., K. J. Doores, S. Couvreur, R. Martinez Nunez, J. Seow, C. Graham, S. Acors et al. 2020. “Estimates of the Rate of Infection and Asymptomatic COVID-19 Disease in a Population Sample from SE England.” *Journal of Infection* 81 (6): 931–36.

Wilde, H., T. Mellan, I. Hawryluk, J. M. Dennis, S. Denaxas, C. Pagel, A. Duncan et al. 2021. "The Association between Mechanical Ventilator Availability and Mortality Risk in Intensive Care Patients with COVID-19: A National Retrospective Cohort Study." medRxiv 2021.01.11.21249461.

Yanes-Lane, M., N. Winters, F. Fregonese, M. Bastos, S. Perlman-Arrow, J. R. Campbell, and D. Menzies. 2020. "Proportion of Asymptomatic Infection among COVID-19 Positive Persons and Their Transmission Potential: A Systematic Review and Meta-analysis." *PLoS One* 15 (11): e0241536.

Zhou, F., T. Yu, R. Du, G. Fan, Y. Liu, Z. Liu, J. Xiang et al. 2020. "Clinical Course and Risk Factors for Mortality of Adult Inpatients with COVID-19 in Wuhan, China: A Retrospective Cohort Study." *The Lancet* 395 (10229): 1054–62.

Central Bank Independence and Systemic Risk*

Alin Marius Andrieş,[a,b] Anca Maria Podpiera,[c]
and Nicu Sprincean[a]
[a]Alexandru Ioan Cuza University of Iaşi
[b]Institute for Economic Forecasting, Romanian Academy
[c]World Bank

We investigate the relationship of central bank independence and banks' systemic risk measures. Our results support the case for central bank independence, revealing that central bank independence has a robust, negative, and significant impact on the contribution and exposure of banks to systemic risk. Moreover, the impact of central bank independence is similar for the stand-alone risk of individual banks. Secondarily, we study how the central bank independence affects the impact of selected institutional, country, and banking system indicators on these systemic measures. The results show that there might be trade-offs between central bank independence and a central bank's financial stability mandate and that central bank independence may exacerbate the effect of a crisis on the contribution of banks to systemic risk, hence the need for a coordinated interaction between central banks and the governments. We also find that an increase in central bank independence can ameliorate the effects of environments characterized by a low level of financial freedom or high market power that, by themselves, enhance the systemic risk contribution of banks.

JEL Codes: G21, E58, G28.

*We thank Elizabeth Berger, Felicia Ionescu, Iikka Korhonen, Camelia Minoiu, Zuzana Fungáčová, Steven Ongena, and Răzvan Vlahu, as well as participants at the ERMAS 2019, 2020 IBEFA Summer Conference, 2020 Virtual Annual Congress of the European Economic Association, and 2020 FMA Virtual Conference, and participants at the research seminars at the National Bank of Romania and Bank of Finland for their valuable comments and suggestions. We are indebted to Tobias Adrian (editor) and the two anonymous referees for detailed comments and suggestions that led to considerable improvements in the paper. The views expressed in this paper are those of the authors and do not reflect the views of Alexandru Ioan Cuza University of Iaşi, the World Bank, or its affiliated organizations. Part of this research was completed while Andrieş was a visiting researcher at the Bank of Finland Institute for Economies in Transition (BOFIT); the kind hospitality was greatly appreciated. Sprincean acknowledges financial support from the Romanian National Authority for Scientific Research and Innovation, *CNCS – UEFISCDI – PN-III-P4-ID-PCE2020-0929.* Author e-mails: alin.andries@uaic.ro; apodpiera@worldbank.org; sprincean.nicu@uaic.ro.

1. Introduction

No wonder politicians often find the Fed a hindrance. Their better selves may want to focus on America's long-term prosperity, but they are far more subject to constituents' immediate demands. That's inevitably reflected in their economic policy preferences. If the economy is expanding, they want it to expand faster; if they see an interest rate, they want it to be lower — and the Fed's monetary discipline interferes.

– *Alan Greenspan (2007)*[1]

The 2007–09 global financial crisis was followed by a low-inflation environment, aggressive use of unconventional monetary measures by central banks, and an increased number of central bank responsibilities. These stirred up the debate about the importance of maintaining central bank independence (de Haan et al. 2018). Allegations of distributional effects across different segments of population generated by the unconventional measures[2] employed by the central banks and of central banks over-stretching their mandates in their response to the financial crisis escalated this debate (Mersch 2017). We ask whether these new and revised mandates, particularly the financial stability mandate, are justifications for undermining the independence of central banks.

Central bank independence (CBI) has been credited with maintaining price stability and, more recently, with helping in recovery from the financial crisis.[3] Indeed, independence is one of the three institutional underpinnings[4] to which the success of inflation targeting in delivering low and stable inflation rates has been attributed (Mishkin 2004). A large empirical literature shows that inflation and central bank independence are negatively related in both developed

[1]Greenspan (2007, pp. 110–11).

[2]The unconventional measures involved the purchasing of large amount of public debt in the secondary markets.

[3]Surveys are provided by Berger, de Haan, and Eijffinger (2001), Cukierman (2008), Fernández-Albertos (2015), and de Haan and Eijffinger (2016).

[4]The other two institutional underpinnings are (i) clear mandate to maintain price stability and commitment to achieve that goal; (ii) central bank accountability (Mishkin 2004).

and developing countries (Cukierman 2008). Central bank independence is also recognized as a key factor for lower volatility of output (Bernanke 2004). It is usually measured along two dimensions: political and economic independence.

Political independence refers to the central bank's discretion in designing and implementing policies consistent with the monetary stability goal. It shields the central bank from short-term political pressures. *Economic independence* relates to the freedom of the central bank for choosing the set of instruments consistent with monetary policy (Masciandaro and Romelli 2015).

Recently, a significant number of reforms increased the range of powers of central banks in the areas of prudential supervision, financial stability,[5] and macroprudential policy, which, unlike monetary policy, can require the central bank to coordinate with the government and other regulatory institutions. This increases the challenge of preserving central bank independence. In 2013, for example, the Bank of Japan agreed to coordinate policy with the government (Condon 2019). Issing (2018) considers that "a permanent threat for independence relates to the coordination with fiscal policies." More than half of respondents in an expert survey agreed with the statement that there will be significant changes in the independence of monetary policy in the United Kingdom and the euro zone in the foreseeable future (de Haan et al. 2017). Goodhart and Lastra (2018) add the rise in populism to the sources that dented the consensus for central bank independence.

This paper aims to contribute to the policy debate about the importance of maintaining central bank independence by analyzing empirically its significance for financial stability, more specifically for containing banks' systemic risk. It also attempts to shed some light on the channels through which CBI could lessen this. Doumpos, Gaganis, and Pasiouras (2015) distinguish between a direct impact that CBI could have on the "well-functioning of banks" in cases where the central bank is involved in supervision and an indirect influence on bank soundness through monetary policy and price stability, regardless of "whether prudential supervision is assigned to

[5] Toniolo and White (2015) provide a historical perspective of the financial stability mandate.

the central bank or not." We add that a direct impact could work also through a financial stability mandate.

The financial stability mandate for containing potential systemic risk returned to prominence after public authorities, both national and supranational, intervened during the financial crisis (Goodhart 2011; Capie and Wood 2013).[6] While financial stability was already an element of most central bank mandates before the crisis, it was secondary to the prime objective of delivering price stability (Bolton et al. 2019). As an example, the Federal Reserve's role in financial system stability started in the late 1960s. Despite the stepping up of "unprecedented actions" during the 2007–08 financial crisis, questions remained as to the proper scope and design of the mandate (Haltom and Weinberg 2017).

Systemic financial risk measures developed in the wake of the crisis made it possible to quantify the contribution and exposure of banks to systemic risk, as well as improve the regulatory framework. In parallel, there has been major interest in assessing the determinants of systemic risk. Weiß, Bostandzic, and Neumann (2014) find little empirical evidence in favor of commonly identified factors such as bank size, leverage, non-interest income, and the quality of a bank's credit portfolio as determinants of systemic risk across financial crises. Instead, institutional structures and characteristics of the regulatory regimes seem to be the important factors.

While there is a substantial literature on the relationship of CBI and inflation, studies on the nexus of CBI and systemic risk are scarce. Cihak (2010) attributes this to the complex relationship of price stability and financial stability: while in the long run the price stability can be seen as an important component of the financial stability, in the short term and medium term there can be trade-offs between these two mandates. Central banks also have less control over policy outcomes with respect to financial stability, as they must share responsibilities with other agencies, hence it is unclear how more CBI affects financial stability. At the same time, greater CBI reduces the likelihood of political constraints on the conduct

[6]It has been argued that systemic risk is a particular feature of financial systems (de Bandt and Hartmann 2000). It emerges when all parts of the financial system, including multiple markets and institutions, are simultaneously distressed (Patro, Qi, and Sun 2013).

of monetary policy or of capture by financial-sector players, and thereby allows timely actions to prevent a financial crisis. Restraining the influence of politicians on central bank policy removes the danger that a financial crisis can be used as an issue in the reelection campaign of the incumbent government (Keefer 2001).

The theoretical work also presents mixed conclusions. In making the case for greater CBI, Ueda and Valencia (2014) find that if a central bank or macroprudential regulators are not politically independent, a social optimum is unachievable.[7] In contrast, Berger and Kißmer (2013) find that central bankers with greater independence are more likely to refrain from implementing preemptive monetary tightening to maintain financial stability.

There is a small body of empirical work analyzing the effect of CBI on financial stability, and more generally on the functioning of financial markets. Most of this literature supports a positive effect of the CBI. Khan, Khan, and Dewan (2013) suggest that an increase in the autonomy of the central bank lowers the probability of a banking crisis.[8] In the same vein, Garcia-Herrero and Del Rio Lopez (2003) and Klomp and de Haan (2009) observe a positive relationship between the degree of central bank independence and financial stability. Doumpos, Gaganis, and Pasiouras (2015) find that central bank independence exercises a positive impact on bank soundness. Empirical papers in this area offer mixed findings as to the impact of CBI on stock market performance. Förch and Sunde's (2012) results indicate a positive effect of CBI over stock market returns, while Papadamou, Sidiropoulos, and Spyromitros (2017) find that enhanced CBI increases stock market volatility. Using governor turnover as a proxy for limited actual independence, Moser and Dreher (2010) show that higher turnover affects financial markets negatively. Kuttner and Posen (2010) also observe that the lack of independence of the central bank enhances the disruptive impact of the frequent appointments of central bank governors on exchange rates and bond yields.

[7]The "social optimum" described in the paper requires separating price and financial stability objectives.

[8]Arnone et al. (2009) argue that there is a difference between central bank independence (lack of institutional constraints) and central bank autonomy (operational freedom). These terms, however, are used interchangeably in the literature.

To examine how the CBI affects banks' systemic risk, our approach looks at systemic risk from three angles: the contribution of banks to systemic risk, the exposure of banks to systemic risk, and the stand-alone risk of banks. Every central bank has its own set of objectives such as price stability, financial stability, or full employment. Such objectives may conflict on occasion (e.g., activist policy, countercyclical monetary policy). Our intuition is that a more independent central bank is better at pursuing its full palette of objectives.

In addition, we contribute to the extant literature concerned with the determinants of the systemic risk by analyzing a global sample of banks which includes banks from both emerging and developed countries over an extensive period of time, thus enriching the current literature that tends to concentrate on developed countries (Broz 2002; Pistoresi, Salsano, and Ferrari 2011) or is mainly cross-sectional (Crowe and Meade 2007). Our sample consists of 323 banks in 40 countries over a period of 14 years (2001–14). This period comprises the dot-com crisis, the recent global financial crisis (2007–09), and the sovereign debt crisis in Europe (2010–13).

We also analyze how central bank independence affects the impact of various institutional, country, and banking system indicators on systemic risk. The interaction with institutional variables such as the role of central bank in financial stability and the level of a country's development could shed light on potential channels though which CBI affects systemic risk.[9]

We document a negative and significant influence of central bank independence on major systemic and individual risk measures (ΔCoVaR, SRISK, MES, VaR, and Beta) computed for individual banks, i.e., central bank independence is desirable for containing systemic risk, hence for maintaining financial stability. Our findings are robust after controlling for nesting and potential endogeneity issues. At the same time, we find evidence of trade-offs between CBI and central banks having financial stability mandates that often involves coordination with the government. This indicates that CBI's effect on systemic risk works rather through the prudential supervision, especially when banking sector supervision is within the central

[9] We thank a reviewer for suggesting to analyze these potential channels.

bank, or through monetary policy preferences. An additional finding that a higher degree of central bank independence may exacerbate the effect of a crisis on the systemic risk contribution of banks adds to the evidence that central bank coordination with fiscal policy is needed for prevention of or in resolving a financial crisis. We further show that central bank independence mitigates the systemic risk contribution of banks in countries with a low level of financial freedom or where banks hold substantial market power. The remainder of our paper is structured as follows. In Section 2, we describe the methodology, sample, and data employed. In Section 3, we discuss the empirical findings. Section 4 presents the concluding remarks.

2. Data, Sample, and Methodology

This section presents the data used and the econometric model. We explain the framework employed to estimate the impact of CBI on how much banks contribute to systemic risk and their exposure to systemic risk. We also describe our measures of CBI and systemic risk.

2.1 Sample and Data

We analyze the potential impact of CBI on systemic risk in a panel framework using bank-level data for 14 years (2001–14). The final sample in the regression analysis is composed of 323 publicly listed banks with the mean size of USD 220 billion at the end of 2014. All banks are active at the international or national level and represent 40 countries (Table A.1 in the appendix). The final sample is a refinement of an original sample comprising the 560 banks in 66 countries identified in Thomson Reuters Datastream as "global banks."[10] We excluded banks that either failed to report daily market capitalization consistently throughout the observation period or had more than 25 percent of their quarterly balance sheets missing in the Worldscope data set.

[10]Ticker *G#LBANKSWD.*

2.2 Econometric Framework

Our data set has a clear hierarchical structure with individual banks nested in countries over a number of years. Similar to Doumpos, Gaganis, and Pasiouras (2015), we employ a hierarchical linear modeling (HLM) approach. This is one of the main empirical approaches that models clustered data, accounting for data having various levels of aggregation and controlling for potential dependency due to nesting effects. One of the main advantages of multilevel modeling comes with unbalanced data. In our sample, there are different sample sizes in different countries. Moreover, the HLM estimation does not require residuals to be independent (Mourouzidou-Damtsa, Milidonis, and Stathopoulos 2019).

The HLM approach has been recently applied in cross-country studies that examine firm performance (Kayo and Kimura 2011; Li et al. 2013; van Essen, Engelen, and Carney 2013; Marcato, Milcheva, and Zheng 2018), as well as bank risk-taking and stability (Doumpos, Gaganis, and Pasiouras 2015; Mourouzidou-Damtsa, Milidonis, and Stathopoulos 2019). It is appropriate for explaining the variance at all levels of aggregation and deals with the fact that there are inherent differences in banking systems in different countries. The practices of banks in Islamic countries that comply with Sharia law and business models may differ only nominally from conventional banking in some instances, and quite substantially in others. Financial markets provide the bulk of financing in the United States, while in Europe and many Asian countries, the banking system plays a dominant role, so banks tend to be preferred by companies in raising project financing. Langfield and Pagano (2016) show that Europe is more prone to systemic risk because of its dependence on bank-based financial structure.

The estimated model has the following form:

$$SR_{ij,t} = \underbrace{\alpha_0 + \alpha_1 \times CBI_{j,t-1} + \gamma \times X_{ij,t-1} + \delta \times Z_{j,t-1}}_{fixed\ \ components} + \underbrace{u_{ij} + e_j + \varepsilon_{ij,t}}_{random\ \ components}, \quad (1)$$

where $SR_{ij,t}$ is the systemic risk measure of bank i from country j in year t and $CBI_{j,t-1}$ is the main variable of interest that quantifies the degree of central bank independence, i.e., CBI index and its subcomponents (*personnel independence*, *central bank objectives*, *policy independence*, and *financial independence*), from country j in year $t-1$. For all banks, including the international banks, country j is the country where the bank is incorporated.[11]

$X_{ij,t-1}$ is a $(k \times 1)$ vector of lagged bank-level control variables (bank size, credit risk ratio, profitability, capitalization, and the funding structure) associated with systemic risk in the literature (Beck, Demirgüç-Kunt, and Levine 2006; Berger, Klapper, and Turk-Ariss 2009; Farhi and Tirole 2012; Laeven, Ratnovski, and Tong 2016; Xu, Hu, and Das 2019).

$Z_{j,t-1}$ is a $(k \times 1)$ vector that includes banking system variables (bank concentration and level of financial intermediation) associated with systemic risk in the banking sector (Boyd, De Nicolo, and Jalal 2006; Beck, De Jonghe, and Mulier 2017), standard country-level control variables (real GDP growth and inflation), and a variable that captures the degree of central bank involvement in microprudential supervision (with the maximum value assigned when all supervisory responsibilities are consolidated under the roof of the central bank). Melecky and Podpiera (2015) show that having banking supervision in the central bank can help prevent systemic banking crises, while Doumpos, Gaganis, and Pasiouras (2015) show that central bank involvement in supervision has a positive impact on bank soundness.

Table A.2 in the appendix describes the variables and the sources of data. Table A.3 presents the summary statistics. Table A.4 shows the correlation matrix of the regressors.

We use lagged independent variables (except for crisis dummy variables) to control for the speed of adjustment of systemic risk indicators and to account for potential endogeneity issues (Melecky and Podpiera 2013). The random variables u_{ij} and e_j allow the intercept $(\alpha_0 + u_{ij} + e_j)$ to be random and unique to every bank and country. $\varepsilon_{ij,t}$ is the error term. The model assumes the intercept is random and slopes are fixed. The model is fit using the maximum

[11]For international banks, we capture only the effect of the CBI index in the country where the banks are incorporated. We acknowledge that the CBI indices from the countries where they operate would have an effect on their SR measures, but we cannot account for this here.

likelihood (ML) estimation of the variance components of Hartley and Rao (1967). To mitigate the problem of outliers, we winsorize all variables within the 1 percent and 99 percent percentiles.

In our analysis of whether CBI affects the impact of selected variables on measures of systemic risk, we focus on the role of the central bank in financial stability, level of development (including financial development), crisis (the 2007–09 global financial crisis and sovereign debt crisis in Europe), and two relevant macroeconomic and banking system characteristics (market power in the banking system and exchange rate regime) by including these variables and their interaction with CBI in the benchmark regression. The model has the following specification:

$$SR_{ij,t} = \underbrace{\begin{array}{l}\alpha_0 + \alpha_1 \times CBI_{ij,t-1} + \alpha_2 \times CBI_{ij,t-1} \times W_{j,t-1} \\ \quad + \gamma \times X_{ij,t-1} + \delta \times Z_{j,t-1}\end{array}}_{fixed\ \ components} + \underbrace{u_{ij} + e_j + \varepsilon_{ijw,t}}_{random\ \ components}, \tag{2}$$

where $W_{j,t-1}$ is the vector of the selected variables.

2.3 Measures of Banks' Systemic Risk

It is recognized that all systemic risk measures fall short in capturing the multifaceted nature of systemic risk, and further that different measures of systemic relevance can lead to conflicting results in identification of systemically important financial institutions (Benoit et al. 2013). We therefore employ several measures of systemic importance: (i) two measures of systemic risk contribution (ΔCoVaR and SRISK); (ii) two measures of systemic risk exposure (MES and Exposure-ΔCoVaR), and two measures of banks' individual (or stand-alone) risk (VaR and Beta) estimated for each bank over the 2001–14 period.[12]

[12]Bisias et al. (2012) provide an extensive survey of 31 measures of systemic risk.

2.3.1 Systemic Risk Contribution

ΔCoVaR. The first indicator considered for systemic risk contribution is the Conditional Value at Risk (CoVaR) of Adrian and Brunnermeier (2016). It is based on the well-known Value at Risk (VaR) measure that involves the estimation of each bank's q^{th} quantile of the following loss function:[13]

$$q = \Pr\left(R^{i}_{Market\ Assets,t} \leq VaR^{i}_{q,t}\right), \tag{3}$$

where $R^{i}_{MarketAssets,t}$ is the bank's i market value of total assets at time t determined by adjusting the book value of total assets by the ratio between market capitalization (market value of equity) and the book value of equity. Similarly, the VaR of the system can be computed as follows:

$$q = \Pr\left(R^{System}_{Market\ Assets,t} \leq VaR^{System}_{q,t}\right). \tag{4}$$

VaR, which expresses the maximum possible loss (as a percent of the market value of total assets) that a bank or the system could register for a given confidence level over a specific period of time, is the loss that can be found in the left tail of the market value of total assets distribution function.

We focus on the daily change of the market value of total assets of institution i from $t-1$ to t. Because total assets and book equity have quarterly frequencies while market equity has a daily frequency, we transform the first two accounting measures into daily frequencies through linear interpolation between two consecutive quarters.[14] We eliminate banks that have missing total assets or equity data for two or more consecutive quarters.

VaR is an indicator that was used in the context of microprudential supervision. It therefore fails to capture the risk of the whole system. To assess contagion spillovers from a bank to the whole system in the case of a severe reduction of the market value of total assets, we apply the CoVaR methodology. It implies the estimation

[13] Following Adrian and Brunnermeier (2016), all our systemic risk indicators are estimated for a 5 percent quantile.

[14] We perform cubic spline interpolations as a robustness check. The findings remain robust.

of the system's q^{th} quantile of the returns distribution over a given period of time conditional on the event that each bank registers its maximum possible loss. More precisely, we focus on the loss generated by the reduction of banks' market value of total assets under extreme events as in Adrian and Brunnermeier (2016):

$$q = \Pr(R^{System}_{Market\ Assets,q} \\ \leq CoVaR^{System|R^i_{Market\ Assets,t}=VaR^i_{q,t}}_{q,t} | R^i_{Market\ Aseets,t} = VaR^i_{q,t}), \tag{5}$$

where system is defined by the market value of total assets of the sample. Thus, CoVaR is the VaR of the banking system when banks are in distress and thus a good indicator of tail-event linkages between financial institutions (Diebold and Yılmaz 2014).

To compute VaR and CoVaR, we use the quintile regression (QR) developed by Koenker and Bassett (1978). This method allows us to estimate the dependent variable's quantiles conditioned on the explanatory variables. It is more robust in the presence of extreme market conditions (Nistor and Ongena 2020). We use the method of Machado and Santos Silva (2013), which permits standard errors to be asymptotically valid in the presence of heteroskedasticity and misspecification.

The individual and systemic risk of banks have a time-varying component, depending on different risk factors that affect the banking sector. Adrian and Brunnermeier (2016) propose the estimation of VaR and CoVaR to be conditional on several market indices that incorporate information representative for the global financial markets. These indices are lagged one period to control for the speed of adjustment. The market indices we use are presented in Table A.2 in the appendix.

Each bank's VaR is computed using a linear model that captures the dependence of a bank's asset returns on lagged market indices (i.e., vector MI'_{t-1}):

$$R^i_{Market\ \ Assets,t} = \alpha^i + \beta^i \times MI'_{t-1} + \varepsilon^i_t, \tag{6}$$

where α^i is the constant (unobserved characteristics of bank i), β^i is a $(k \times 1)$ vector that captures the bank's i return dependence relationship with the market indices, and ε^i is an i.i.d. error term.

The return of the system can vary with each bank's return and with the lagged market indices as well:

$$R^{System}_{Market\ Assets,t} = \alpha^{System|i} + \delta^{System|i} \times R^{i}_{Market\ Assets,t} + \beta^{System|i} \times MI'_{t-1}\varepsilon^{System|i}_{t}, \quad (7)$$

where $\alpha^{System|i}$ is the constant, capturing the banking system characteristics conditional on bank i, $\beta^{System|i}$ is a $(k \times 1)$ vector of coefficients that captures the system's return dependence relationship with the lagged market indices, $\delta^{System|i}$ reflects the conditional dependence of the system's return on bank'si return, and $\varepsilon^{System|i}$ is the i.i.d. error term.

Running regressions from Equation (6) and Equation (7) for a quantile of 5 percent (distressed periods) and a quantile of 50 percent (median or tranquil state), we obtain the value of regressors to be used in VaR and CoVaR estimations:

$$\widehat{VaR}^{i}_{q,t} = \hat{\alpha}^{i}_{q} + \hat{\beta}^{i}_{q} \times MI'_{t-1} \quad (8)$$

$$\widehat{CoVaR}^{i}_{q,t} = \hat{\alpha}^{System|i}_{q} + \hat{\delta}^{System|i}_{q} \times \widehat{VaR}^{i}_{q,t} + \hat{\beta}^{System|i}_{q} MI'_{t-1}. \quad (9)$$

In the end, each financial institution's contribution to systemic risk (ΔCoVaR) is defined as the difference between VaR of the whole system conditional on the event that the financial institution registers the lowest return at a given confidence level and VaR of the whole system conditional on the event that the financial institution faces the median return:

$$\Delta CoVaR^{System|i}_{q,t} = CoVaR^{System|R^{i}_{Market\ \ Assets}=VaR^{i}_{q,t}}_{q,t} - CoVaR^{System|R^{i}_{Market\ \ Assets=VaR^{i}_{50\%}}}_{q,t}. \quad (10)$$

A greater value of ΔCoVaR is associated with an enhanced contribution to overall systemic risk, and thus increased interconnectedness.

SRISK. The second indicator considered for systemic risk contribution is based on the Systemic Risk Index (SRISK) introduced by Acharya, Engle, and Richardson (2012) and extended to a conditional framework by Brownlees and Engle (2017). SRISK measures the contribution of a bank to wide systemic risk, defined as the loss of a specific bank in terms of capital shortfall, conditioned by the financial system being in distress. To the extent that SRISK captures a bank's performance conditional on the left tail of system returns, it is also close to capturing a bank's exposure to common shocks that affect the whole financial system (Laeven, Ratnovski, and Tong 2016). However, as emphasized by Brownlees and Engle (2017), "when the economy is in a downturn, the bankruptcy of a firm cannot be absorbed by a stronger competitor," hence the obligations will extend to the financial and further to the real sector. The size of the capital shortfall of a bank during a systemic crisis determines how risky it is systemically.

We define the market as the MSCI World Financials Index as in Bostandzic and Weiß (2018). SRISK is conveniently expressed in monetary units, thereby making it reliable in monitoring systemic risk contribution. It also accounts for differences in volatility between individual banks. The capital shortfall of bank i at time t is defined as

$$CS_t^i = kA_t^i - E_t^i = k\left(L_t^i + E_t^i\right) - E_t^i. \tag{11}$$

E_t^i is the market capitalization of the bank (market value of equity), L_t^i is the book value of total liabilities, A_t^i is the implied value of total assets, and k is the prudential capital ratio. As specified above, SRISK is the capital shortfall conditioned by a systemic event, which is the decline of the system below threshold C over time horizon h. Putting these altogether, we have the following expression:

$$\begin{aligned} SRISK_t^i = E_t\left(CS_{t+h}^i | R_{t+1:t+h}^{System} < C\right) = kE_t\left(L_{t+h}^i | R_{t+1:t+h}^{System} < C\right) \\ - (1-k)\,E_t\left(E_{t+h}^i | R_{t+1:t+h}^{System} < C\right). \end{aligned} \tag{12}$$

Further, we assume that when a crisis defined by C hits the financial system, the debt cannot be renegotiated. It follows that

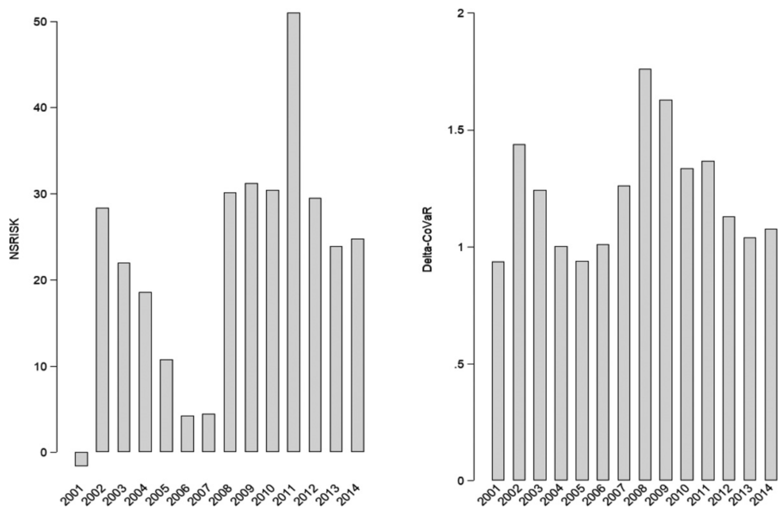
$$SRISK_t^i = kL_t^i - (1-k)E_t^i(1 - LRMES_t^i). \tag{13}$$

$LRMES_t^i$ is the long-run marginal expected shortfall, i.e., the expectation of the bank equity multi-period return conditional on the systemic event. Following Brownlees and Engle (2017), we compute LRMES without simulation as $1-\exp(\log(1-d)\times beta)$, where d is the six-month crisis threshold for the market capitalization of the sample decline when set at 40 percent, and $beta$ is the bank's beta coefficient. The capital prudential ratio k is set at 8 percent in accordance with the Basel Accords. SRISK is estimated using the GJR-GARCH framework with a two-step quasi-maximum likelihood estimation (QMLE). The SRISK indicator of a distressed institution is positive, thereby indicating insufficient working capital. A negative value, in contrast, indicates a capital surplus (no distress).

As in Berger, Roman, and Sedunov (2020), we normalize the SRISK of bank i from country j by its market capitalization and call the new measure NSRISK (normalized SRISK), denoting the proportional capital shortfall per unit of market capitalization. This normalization ensures that the value of the systemic risk indicator is not driven by the market size (market capitalization) of individual banks. Although Acharya, Engle, and Richardson (2012) recommend setting negative SRISK values to zero because they imply a capital surplus and do not contribute to systemic risk, we follow Laeven, Ratnovski, and Tong (2016) and choose not to do so because this would result in a series with many zeroes that econometrically would be hardly to explain and result in biased estimations. Moreover, negative NSRISK values are useful in measuring the relative contribution of the banks to systemwide distress. Thus, our next approach is to construct two synthetic systemic risk measures using factor analysis that include NSRISK (see Section 3.4), and the series that contain only zeroes (capital surplus only) will be discarded because they have zero variance.

Figure 1 shows the evolution of average banks' systemic risk contribution, defined by ΔCoVaR and NSRISK during the 2001–14 period. One can observe that both ΔCoVaR and NSRISK increased during periods of distress such as the dot-com crisis and global financial crisis. However, the peaks differ for the two indicators, perhaps reflecting the differences between the two measures, with the ΔCoVaR closer to capturing contagion risks and NSRISK closer to capturing the exposure to common shocks affecting the whole financial sector. For ΔCoVaR, the peak is in 2008, the year associated with the Lehman Brothers default and the onset of global financial crisis. For NSRISK, the peak is in 2011 when there was a sovereign

Figure 1. Evolution of Average Systemic Risk Contribution by Year



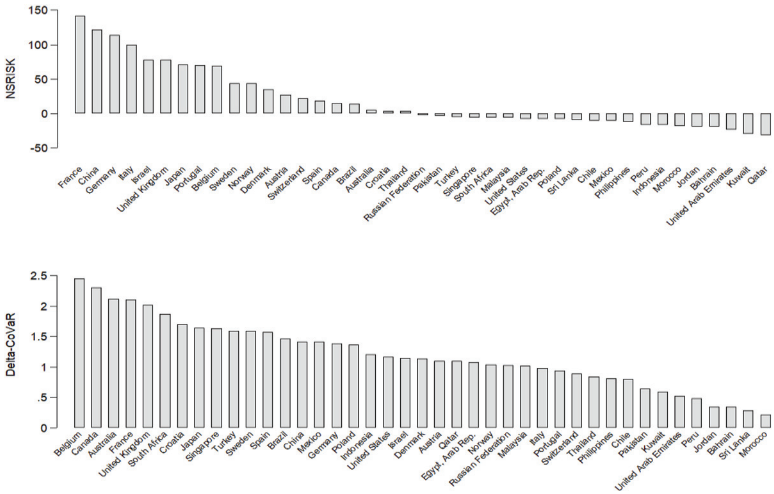
debt crisis in Europe characterized by high government debt and high yield spreads in government securities. Continent-wise, European banks had the largest average contribution to systemic risk over the whole period, defined by NSRISK. Asian banks were the second largest in terms of average contribution. However, Australian banks were the riskiest in terms of ΔCoVaR, followed by those from Europe.

In terms of average contribution to systemwide distress by country (Figure 2), French banks had the highest capital shortfall per unit of market capitalization in the 2001–14 period, following by bank based in China and Germany. Banks based in the United Arab Emirates, Kuwait, and Qatar had the highest capital surplus per unit of market capitalization. As for ΔCoVaR, Belgian, Canadian, and Australian banks were the main contributors, on average, to systemic risk, whereas the banks from Bahrain, Sri Lanka, and Morocco contributed least to systemic risk.

2.3.2 Measure of Systemic Risk Exposure

Systemic risk exposure is proxied by marginal expected shortfall (MES) of Acharya, Engle, and Richardson (2017) and

Figure 2. Average Systemic Risk Contribution by Country



Exposure-ΔCoVaR of Adrian and Brunnermeier (2016). MES is defined as the average return on an individual bank's stock on days when the market (MSCI World Financials Index) experiences a loss greater than a specified threshold C indicative of market distress.

$$MES^i_{t-1} = E_{t-1}\left(R^i_t | R^{System}_t < C\right), \tag{14}$$

where R^i_t is the return of bank i at time t and R^{System}_t is the return of the financial system, defined as MSCI World Financials Index. We model the bivariate process of bank and market returns as follows:

$$R^{System}_t = \sigma^{System}_t \varepsilon^{System}_t \tag{15}$$

$$R^i_t = \sigma^i_t \varepsilon^i_t = \sigma^i_t \rho^i_t \varepsilon^{System}_t + \sigma^i_t \sqrt{1 - \rho^2_{i,t}} \xi_{i,t}. \tag{16}$$

σ^i_t and σ^{System}_t are the volatilities of bank i and the financial system, respectively; ρ^i_t is the correlation coefficient between the return of bank i and the return of the system; and ε^{System}_t, ε^i_t, and $\xi_{i,t}$ are the error terms which are assumed to be i.i.d. It follows that

$$
\begin{aligned}
MES_{t-1}^{i} &= E_{t-1}\left(R_t^i | R_t^{System} < C\right) \\
&= \sigma_t^i E_{t-1}\left(\varepsilon_t^i \middle| \varepsilon_t^{System} < \frac{C}{\sigma_t^{System}}\right) \\
&= \sigma_t^i \rho_{i,t} E_{t-1}\left(\varepsilon_t^i \middle| \varepsilon_t^{System} < \frac{C}{\sigma_t^{System}}\right) \\
&\quad + \sigma_t^i \sqrt{1-\rho_{i,t}^2} E_{t-1}\left(\xi_t^i \middle| \varepsilon_t^{System} < \frac{C}{\sigma_t^{System}}\right). \qquad (17)
\end{aligned}
$$

As in Benoit et al. (2013), we consider the threshold C equal to the conditional VaR of the system return, i.e., VaR (5 percent), which is common for all institutions. Conditional volatilities of the equity returns are modeled using asymmetric GJR-GARCH models with a two-step quasi-maximum likelihood estimation. The time-varying conditional correlation is modeled using the dynamic conditional correlation (DCC) framework of Engle (2002). The higher the MES, the higher the exposure of the bank to systemic risk.

Exposure-ΔCoVaR (eΔCoVaR) works in the opposite direction with ΔCoVaR, denoting the system's contribution to bank i or, alternatively, the exposure of bank i to the system. It is defined as the difference between VaR of the financial institution i conditional on the event that the system is in distress (5 percent worst outcomes), and VaR of the financial institution i conditional on the event that the system faces the median return (i.e., tranquil state):

$$
\begin{aligned}
e\Delta CoVaR_{q,t}^{i|System} &= CoVaR_{q,t}^{i|R_{Market\ Assets}^{System}=VaR_{q,t}^{System}} \\
&\quad - CoVaR_{q,t}^{i|R_{Market\ Assets=VaR_{50\%}^{System}}^{System}}. \qquad (18)
\end{aligned}
$$

2.3.3 Banks' Individual or Stand-Alone Risk

We also analyze how central bank independence influences individual risk of the banks (i.e., a microprudential approach). Before the global financial crisis, the microprudential paradigm (Basel I and Basel II approaches) was used to describe financial stability. It assumed that financial instability is exogenous to the financial system and that risk should be assessed on an individual basis. Its main drawback was the fact that it ignored spillover effects between institutions—a cause often cited as the main driver of the 2007–09 recession. We define individual risk as the maximum possible loss as a percent of the total market equity a bank could register for a given confidence level (95 percent) over a specific period of time, i.e., its VaR. We compute VaR using the same methodological approach employed for MES, modeling conditional volatilities of the equity returns with the asymmetric GJR-GARCH model. VaR is expressed as a positive number, higher values being associated with enhanced individual risk. In addition, we employ the dynamic conditional beta using the DCC framework of Engle (2002) to capture the conditional co-movement between each bank and the market (MSCI World Financials Index), where the GJR-GARCH process is employed to account for the conditional heteroskedasticity. Higher values of beta denote increased risk of bank i in comparison with the market.

2.4 Central Bank Independence Measures

In general, measures of the degree of central bank independence are built using de facto and de jure measures of independence. *De facto indices* associate the independence of central banks with the autonomy of its governor. Thus, a high rate of governor turnover is associated with low central bank independence. *De jure indices* capture central bank legislative requirements such as the objective function of the central bank, the procedures for the appointment of the governor and other board members, designation of the authority responsible for monetary policy, as well as procedures for resolving conflicts between the central bank and the government. The de jure index of CBI proposed by Cukierman, Webb, and Neyapti (1992) has been widely embraced by researchers. The authors compute the CBI index for 21 developed and 51 developing countries. The index takes values between zero and one, where zero means no independence and one means perfect independence (see Cukierman, Webb, and Neyapti 1992 for a detailed description of the index).

Here, we use the CBI index computed by Bodea and Hicks (2015). It expands the CBI index of Cukierman, Webb, and Neyapti (1992) to comprise 80 countries covering a period from 1972 to 2015. Similar to this approach, Garriga (2016) codes the central bank legislation for more countries (182 countries), but a slightly shorter period (1970 to 2012). We opted for using Bodea and Hicks's (2015) index because it covers the longest period (more observations for after Lehman Brothers period) and has a fair overlap of countries with our database. We also employ Garriga's (2016) index for robustness check.

The aggregated CBI index of these both databases is a weighted index of four components and 16 criteria in total:

- *Governor Characteristics (Personnel Independence):* (i) length of governor's term; (ii) entity delegated to appoint him/her; (iii) provisions for dismissal; and (iv) ability to hold another office in the government. The weight in the index is 0.2.
- *Policy Formulation Attributions (Policy Independence):* (v) whether the central bank is responsible for monetary policy formulation; (vi) rules concerning resolution of conflicts between the central bank and government and (vii) the degree of central bank participation in the formulation of the government's budget. The weight in the index is 0.15.
- *Central Bank Objectives:* (viii) monetary stability as one of the primary policy objectives. The weight in the index is 0.15.
- *Limitations on Central Bank Lending to the Public Sector (Financial Independence):* (ix) advances and (x) securitized lending; (xi) authority having control over the terms (maturity, interest rate, and amount) of lending; (xii) width of circle of potential borrowers from the central bank; (xiii) types of limitations on loans, where such limits exist; (xiv) maturity of possible loans; (xv) limitations on interest rates applicable to lending; and (xvi) prohibitions on central bank participation in the primary market for government securities. The weight in the index is 0.5.

The CBI index and its subcomponents represented in Figure 3 begin a remarkable increase in 2001. The main difference is in terms of *personnel independence*, where the index showed a downward trend until 2006. Note the sharp drop in value of CBI index starting

Figure 3. Evolution of Average Weighted CBI Index and Its Subcomponents by Year

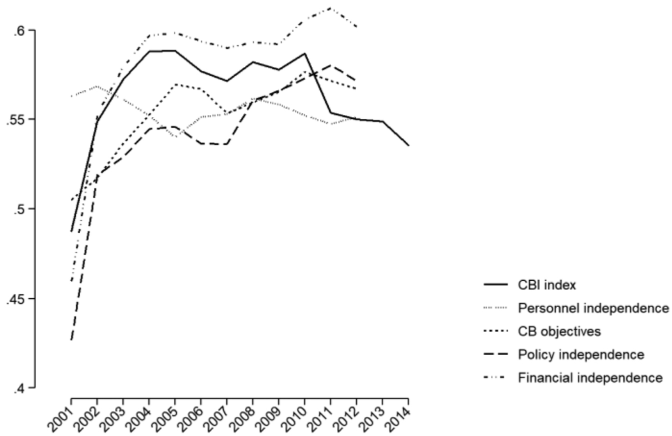
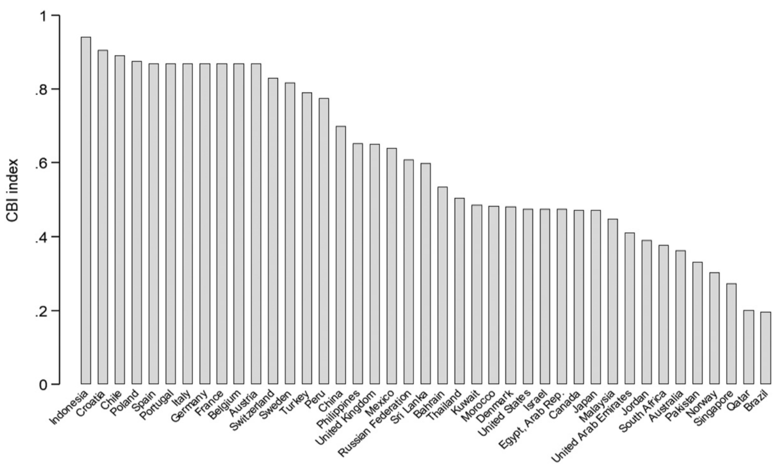


Figure 4. Average Weighted CBI Index by Country



in 2011. This is likely due to the fact that the values for European Central Bank (ECB) that we substitute for countries within the euro zone were only available through 2010. The most independent central banks are, on average, the central banks of Indonesia, Croatia, and Chile. The least independent central banks are those of Singapore, Qatar, and Brazil (Figure 4).

3. Main Empirical Results

3.1 Base Results

The benchmark results presented in Tables 1 and 2 show the negative impact of CBI measures on the measures of banks' contribution to systemic risk (ΔCoVaR and NSRISK).[15] Each of these tables report the outcome of the estimations for the model described in Equation (1) corresponding to the five CBI measures. As the degree of central banks' independence increases, banks' contribution to systemwide distress decreases. This is strongly valid for all subcomponents of the CBI index and for the weighted index, except for *financial independence* in the case of ΔCoVaR, where its coefficient, although with a negative sign, lacks statistical significance. A one-standard-deviation increase in the CBI index leads to decline in the systemic contribution of the banks by 13.23 percent as measured by ΔCoVaR, and by 21.66 percent as measured by NSRISK. Our results are in line with those of Klomp and de Haan (2009), suggesting a positive link between central bank independence and financial stability, as well as with those of Doumpos, Gaganis, and Pasiouras (2015), who find that central bank independence exercises a positive impact on bank soundness. The LR test is statistically significant for all models, meaning that the estimated model through HLM is different from the standard ordinary least squares (OLS) regression, favoring the multi-level specification.

The estimated coefficients for control variables yield some noteworthy results. The impact of *size*, while significant, has opposite signs in the two models, i.e., a negative value in the NSRISK model and a positive value in the ΔCoVaR model (only in two models out of five the coefficient of the *size* variable is statistically significant). As discussed earlier, NSRISK is closer to the exposure to common shocks that affect the whole financial system, whereas ΔCoVaR is linked to contagion risks (Laeven, Ratnovski, and Tong 2016). Hence, the negative sign in the NSRISK model could suggest that larger banks may diversify more efficiently and enjoy

[15] Note that the number of the banks and countries differs in concordance with the central bank independence measure employed. The time span of the CBI index is from 2001 to 2014, whereas for its subcomponents the availability of the data is from 2001 to 2012.

easier access to capital markets, thereby putting them in a more solid position than smaller banks in the event of a downturn. This assessment is in line with Shim (2013). On the other hand, size seems to increase contribution to systemic risk contagion. This comports with the "too-big-to-fail" hypothesis, whereby large banks confident of being bailed out by government in the event of financial distress having greater incentive to engage in excessive risk-taking behavior and thereby increase the overall systemic risk in the financial sector (Farhi and Tirole 2012). This finding is consistent with that of Laeven, Ratnovski, and Tong (2016).

As expected, deterioration in the quality of the loan portfolio enhances both measures of banks' contribution to systemic risk. Better *profitability*, higher *capitalization*, and a funding structure that is mainly based on deposits reduce banks' systemic distress. *Profitability*, however, is significant only in explaining NSRISK: it decreases exposure to common shocks but does not prevent systemic risk contagion. In terms of macroeconomic and banking system control variables, higher economic growth helps banks reduce their systemic importance, whereas *inflation* amplifies exposure to common shocks.

Bank concentration's coefficient is significant but has opposite signs in the two models: negative for explaining systemic risk contagion and positive for explaining the exposure to common shocks. Intuitively, this makes sense. Fewer banks in the system make them more prone to exposure to common shocks but have less impact on contagion. This also mimics the mixed results in the literature. Beck, De Jonghe, and Mulier (2017) find concentration of bank assets to be a key contributor to accumulation of systemic risk in the banking sector. Boyd, De Nicolo, and Jalal (2006) claim probability of bank default is positively and significantly related to concentration. Beck, Demirgüç-Kunt, and Levine (2006) find that the likelihood of a banking crisis is reduced in countries with concentrated banking sectors.

Elevated levels of financial intermediation amplify the risk banks pose to the whole financial system, consistent with the literature.[16]

[16]Previous studies (e.g., Reinhart and Rogoff 2009; Jordà, Schularick, and Taylor 2013) emphasize that the credit boom is a first-order factor in explaining banking crises.

Table 1. Results for the Base Model: ΔCoVaR

Dependent: ΔCoVaR	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Fixed-Effects Parameters					
CBI Index (t–1)	−0.575***				
	(0.157)				
Personnel Indep. (t–1)		−0.678***			
		(0.179)			
CB Objectives (t–1)			−0.343***		
			(0.105)		
Policy Indep. (t–1)				−0.699***	
				(0.117)	
Financial Indep. (t–1)					−0.214
					(0.142)
Size (t–1)	0.029	0.035	0.040*	0.030	0.044**
	(0.020)	(0.021)	(0.021)	(0.021)	(0.021)
Credit Risk Ratio (t–1)	0.380	0.769**	0.755**	0.667**	0.854***
	(0.316)	(0.320)	(0.320)	(0.319)	(0.318)
Profitability (t–1)	1.467	1.791	1.557	1.668	1.622
	(1.240)	(1.275)	(1.276)	(1.271)	(1.278)
Capitalization (t–1)	−1.076**	−1.047**	−1.068**	−0.949**	−1.152**
	(0.442)	(0.463)	(0.463)	(0.462)	(0.465)
Funding Structure (t–1)	−0.441***	−0.336**	−0.275**	−0.340**	−0.287**
	(0.129)	(0.135)	(0.134)	(0.134)	(0.134)
Real GDP Growth (t–1)	−0.831*	−1.128**	−1.011**	−1.338***	−1.044**
	(0.462)	(0.484)	(0.483)	(0.483)	(0.484)
Inflation (t–1)	0.001	−0.001	−0.001	−0.002	−0.001
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)

(*continued*)

Table 1. (Continued)

Dependent: ΔCoVaR	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Bank Concentration (t–1)	−0.003***	−0.002***	−0.002***	−0.002***	−0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Financial Intermediation (t–1)	0.001**	0.001**	0.001**	0.001**	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CBIS Index (t–1)	−0.079***	−0.086***	−0.087***	−0.078***	−0.086***
	(0.020)	(0.024)	(0.024)	(0.024)	(0.024)
Constant	0.947*	0.784	0.424	0.946*	0.310
	(0.546)	(0.569)	(0.555)	(0.564)	(0.555)
Random-Effects Parameters					
Country-Level Variance	−1.052***	−0.945***	−1.043***	−1.013***	−1.090***
	(0.194)	(0.175)	(0.191)	(0.186)	(0.197)
Bank-Level Variance	−0.534***	−0.527***	−0.527***	−0.525***	−0.526***
	(0.045)	(0.045)	(0.045)	(0.045)	(0.045)
Residual Variance	−0.919***	−0.904***	−0.902***	−0.907***	−0.901***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Observations	3,327	3,233	3,233	3,233	3,233
Countries	40	43	43	43	43
Banks	323	329	329	329	329
LR Test Chi-Square	2,938.761***	2,748.187***	2,800.921***	2,825.238***	2,783.356***

Note: This table reports the results for the base model described in Equation (1). The dependent variable is ΔCoVaR, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

Table 2. Results for the Base Model: NSRISK

Dependent: NSRISK	(1)	(2)	(3)	(4)	(5)
Fixed-Effects Parameters					
CBI Index (t–1)	−0.628***				
	(0.114)				
Personnel Indep. (t–1)		−0.723***			
		(0.131)			
CB Objectives (t–1)			−0.459***		
			(0.076)		
Policy Indep. (t–1)				−0.344***	
				(0.096)	
Financial Indep. (t–1)					−0.363***
					(0.115)
Size (t–1)	−0.036***	−0.040***	−0.039***	−0.040***	−0.038***
	(0.012)	(0.013)	(0.013)	(0.013)	(0.013)
Credit Risk Ratio (t–1)	0.426*	0.949***	0.923***	0.921***	1.082***
	(0.222)	(0.229)	(0.229)	(0.232)	(0.229)
Profitability (t–1)	−3.167***	−3.471***	−3.760***	−3.631***	−3.600***
	(0.839)	(0.877)	(0.876)	(0.879)	(0.879)
Capitalization (t–1)	−2.449***	−2.593***	−2.593***	−2.545***	−2.731***
	(0.294)	(0.312)	(0.312)	(0.314)	(0.314)
Funding Structure (t–1)	−0.678***	−0.689***	−0.642***	−0.647***	−0.642***
	(0.086)	(0.091)	(0.090)	(0.091)	(0.090)
Real GDP Growth (t–1)	−0.954***	−0.610*	−0.475	−0.653*	−0.487
	(0.318)	(0.340)	(0.340)	(0.342)	(0.342)
Inflation (t–1)	0.011***	0.010***	0.010***	0.009***	0.010***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)

(continued)

Table 2. (Continued)

Dependent: NSRISK	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Bank Concentration (t–1)	0.002***	0.003***	0.003***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Financial Intermediation (t–1)	0.005***	0.005***	0.005***	0.005***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
CBIS Index (t–1)	0.003	0.028	0.028	0.030*	0.028
	(0.014)	(0.018)	(0.018)	(0.018)	(0.018)
Constant	1.188***	1.278***	1.070***	1.069***	1.052***
	(0.342)	(0.360)	(0.353)	(0.358)	(0.359)
Random-Effects Parameters					
Country-Level Variance	−0.870***	−0.550***	−0.565***	−0.518***	−0.517***
	(0.130)	(0.125)	(0.125)	(0.128)	(0.129)
Bank-Level Variance	−1.275***	−1.285***	−1.284***	−1.284***	−1.288***
	(0.047)	(0.048)	(0.048)	(0.048)	(0.048)
Residual Variance	−1.305***	−1.270***	−1.271***	−1.267***	−1.266***
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Observations	3,284	3,190	3,190	3,190	3,190
Countries	40	43	43	43	43
Banks	323	329	329	329	329
LR Test Chi-Square	2,188.474***	2,269.242***	2,307.954***	2,163.498***	2,296.290***

Note: This table reports the results for the base model described in Equation (1). The dependent variable is NSRISK, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

CBIS index does not influence exposure to common shocks but negatively affects the systemic risk contagion, i.e., greater central bank involvement in supervision of the financial sector helps reduce tail-event linkages between banks.

3.2 The Impact of Central Bank Independence on Systemic Risk Exposure and Stand-Alone Risk

Our findings for banks' exposure to systemwide distress are in line with those for banks' contribution to systemwide distress, but only in the case of MES (Table 3, column 1). Thus, a central bank that is politically independent is helpful to banks in reducing their exposure to systemic risk. A one-standard-deviation increase in the CBI index decreases systemic exposure of banks by 7.59 percent as measured by MES. In terms of stand-alone risk of individual banks measured by VaR and dynamic conditional beta, central bank independence reduces this in the case of both VaR and Beta estimations (Table 3, columns 3 and 4). A one-standard-deviation increase in the CBI index leads to a fall in banks' VaR by 11.94 percent, whereas a one-standard-deviation increase in the CBI index decreases Beta by 8.49 percent. Regarding the control variables, greater *size*, an increased *credit risk ratio* (MES, VaR, and Beta), *profitability* (eΔCoVaR), higher levels of *credit granted by financial sector* (MES, VaR, and Beta), and *inflation* (VaR) positively affect the risk measures. On the other hand, better *capitalization (*MES, eΔCoVaR, and VaR) *profitability* (Beta), a funding structure dominated by deposits, high *economic growth*, increased *bank concentration*, and a greater *involvement in supervision by the central bank* (MES, eΔCoVaR, and VaR) significantly reduce these measures of distress.

3.3 Further Evidence on the Role of Central Bank Independence on Systemic Risk Contribution

In this section, we analyze five hypotheses regarding how CBI affects the impact of selected institutional, macroeconomic, and banking system characteristics on the measures of the systemic risk of banks. The empirical analysis for each hypothesis includes the variable of interest and its interaction with CBI in addition to the control variables considered so far.

HYPOTHESIS 1. *Central banks' financial stability mandate is meant to manage banks' systemic risk contribution. A heightened central bank independence could reduce this effect because of a potentially lower collaboration with other agencies relevant for the financial stability.*

While central banks are thought to have a natural role in financial stability since monetary policy affects financial conditions and consequently financial stability, historically their de jure mandates have diverged widely (Haltom and Weinberg 2017). To achieve similar levels of performance as well as accountability as for the price stability mandate, an explicit goal for financial stability seems sensible but at the same time "more problematical than inflation targetry, because it is so much harder to monitor, and you cannot really tell whether the authorities are on the right track, or not" (Goodhart and Lastra 2018). At the same time, monetary and prudential policies have traditionally been designed and analyzed in isolation from one another (Collard et al. 2017). A more independent central bank could be more reluctant to share the financial stability responsibilities with other agencies and this could mitigate the beneficial effect of having an explicit mandate on the systemic risk.

To verify this hypothesis, we construct a variable for central bank's financial stability mandate (FSM). We collected data that describe the following three aspects: financial stability mandate or objective, publication of financial stability reports, and the role of central banks in macroprudential committees. For the sources, we used central bank's websites, the databases used in Cerutti, Claessens, and Laeven (2017) and Edge and Liang (2019), the International Monetary Fund's (IMF's) Central Bank Legislation Database, and IMF's Financial Sector Assessment Program reports database. We do not distinguish between whether FSM is a secondary or primary mandate. Out of 40 central banks, 5 have never had an FSM, 11 have had an FSM for the whole period, and 14 acquired an FSM after 2007.

In addition, we look at the effect of the quality of microprudential supervision, proxied by the index developed by Anginer, Demirgüç-Kunt, and Zhu (2014b) on banks' contribution to systemic risk and whether the CBI affects this relationship. This index assesses whether the supervisory authorities have the power and authority

Table 3. Estimation Results for Systemic Risk Exposure (MES and eΔCoVaR) and Individual Risk (VaR and Beta)

	(1)	(2)	(3)	(4)
Dependent Variables	**MES**	**eΔCoVaR**	**VaR**	**Beta**
Fixed-Effects Parameters				
CBI Index (t–1)	−0.550**	−0.039	−0.916***	−0.157**
	(0.275)	(0.209)	(0.350)	(0.075)
Size (t–1)	0.259***	0.080***	0.073**	0.064***
	(0.028)	(0.029)	(0.032)	(0.008)
Credit Risk Ratio (t–1)	2.623***	0.658	2.158***	0.269*
	(0.523)	(0.405)	(0.701)	(0.148)
Profitability (t–1)	−2.017	3.136**	−1.646	−2.705***
	(2.033)	(1.583)	(2.736)	(0.576)
Capitalization (t–1)	−2.113***	−0.951*	−3.185***	0.085
	(0.700)	(0.570)	(0.918)	(0.198)
Funding Structure (t–1)	−1.111***	−0.677***	−1.072***	−0.295***
	(0.202)	(0.169)	(0.259)	(0.057)
Real GDP Growth (t–1)	−2.891***	−1.390**	−3.850***	−0.483**
	(0.779)	(0.588)	(1.067)	(0.220)
Inflation (t–1)	−0.007	−0.019***	0.037***	0.002
	(0.007)	(0.005)	(0.009)	(0.002)

(*continued*)

Table 3. (Continued)

	(1)	(2)	(3)	(4)
Dependent Variables	**MES**	**eΔCoVaR**	**VaR**	**Beta**
Bank Concentration (t–1)	−0.009***	−0.007***	−0.010***	−0.001***
	(0.001)	(0.001)	(0.002)	(0.000)
Financial Intermediation (t–1)	0.009***	−0.002***	0.007***	0.001***
	(0.001)	(0.001)	(0.001)	(0.000)
CBIS Index (t–1)	−0.117***	−0.107***	−0.080*	−0.008
	(0.035)	(0.026)	(0.046)	(0.010)
Constant	−3.301***	0.738	2.395**	−0.815***
	(0.775)	(0.757)	(0.930)	(0.217)
Random-Effects Parameters				
Country-Level Variance	−0.109	−0.519***	−0.170	−1.573***
	(0.131)	(0.174)	(0.150)	(0.138)
Bank-Level Variance	−0.533***	−0.103**	−0.461***	−1.781***
	(0.049)	(0.044)	(0.053)	(0.049)
Residual Variance	−0.399***	−0.683***	−0.076***	−1.660***
	(0.013)	(0.013)	(0.013)	(0.013)
Observations	3,327	3,327	3,327	3,327
Countries	40	40	40	40
Banks	323	323	323	323
LR Test Chi-Square	1,967.876***	3,827.958***	970.073***	1,783.345***

Note: This table reports the results for other measures of bank risk. The dependent variables are MES, eΔCoVaR, VaR, and Beta, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

to take specific preventive and corrective actions.[17] Better microprudential supervision should support the management of banks' contribution to systemic risk as it aims to enhance the resilience of individual financial institutions. Their health is a necessary, but not sufficient, condition for systemwide stability (Osiński, Seal, and Hoogduin 2013).

Hypothesis 2. *A country's level of development directly affects the implementation of financial regulation and hence could help lessen systemic risk. An independent central bank can enhance this effect.*

A country's development is largely associated with the overall level of institutional development and governance. Better governance further provides built-in mechanisms for the implementation of financial regulations, or at the least, it does not hinder this, and therefore could help mitigate the systemic risk. The relationship between development and CBI is not straightforward; countries from across the development spectrum have adopted policies to increase CBI, but their overall effectiveness often hinges on (the lack of) political constrains (Acemoglu et al. 2008). We are testing whether the overall level of development, level of financial freedom, or the level of financial market development neutralizes the effect of CBI documented so far in the analysis and, in addition, whether CBI affects the impact of the development variable on banks' contribution to systemic risk.

To capture this, we focus on two development variables (Real GDP/capita and Financial Freedom index) and three additional indexes that stand for the development of financial markets and institutions (Financial Markets index, Financial Institutions index, and Financial Development index). Table A.2 in the appendix describes these variables.

Hypothesis 3. *A crisis increases the contribution and exposure of banks to systemic risk. CBI can exacerbate this.*

[17]The index is based on World Bank's Bank Regulation and Supervision Surveys. It does not distinguish whether banking supervision is under the roof of the central bank.

While we expect a financial crisis to increase the level of the systemic risk measures, the extent of the impact may depend on several factors, including CBI. CBI is important for preventing the accumulation of systemic risk.[18] But a heightened CBI could undermine necessary coordination of the central bank with other authorities *during* a financial crisis (Balls, Howar, and Stansbury 2018). For example, *the lender of last resort* function of central banks was insufficient during the global financial crisis. Governments had to bail out distressed financial institutions to prevent financial contagion. The crisis period had two phases.[19] During the first phase (July 2007 to the end of 2009), the effects of global financial crisis intensify in Europe (Brei, Gambacorta, and von Peter 2013). The second phase corresponds with the European sovereign debt crisis in Europe, spanning 2010 to 2013 (Cornille, Rycx, and Tojerow 2019). Samarakoon (2017) finds evidence of contagion effects from the European debt crisis to other emerging and developed markets around the world.

HYPOTHESIS 4. *High market power in the banking sector increases the systemic risk contribution of banks, but a higher level of CBI diminishes this effect.*

Banks with "high" market power[20] can charge higher interest rates to firms that can further engage in risky activities, and thereby increase the fragility of the financial system (Boyd and De Nicolo 2005). Anginer, Demirgüç-Kunt, and Zhu (2014a) find that the systemic risk of banks and competition are negatively related. High market power indicates the erosion of competition in the banking sector. We should note the existence of different, competing thoughts on the nexus competition-fragility/stability. Under *competition-fragility* theory,[21] increased bank competition erodes market power and decreases profit margins. This creates incentives

[18]Quintyn and Taylor (2003) find that in almost all systemic financial-sector crisis during 1990s, a major contributing factor was political interference in the supervisory process.

[19]We employ different definitions of crisis, including systemic banking crisis from Reinhart and Rogoff (2011) and Laeven and Valencia (2020). The interaction effect of crisis and CBI remains the same.

[20]We define "high" as values greater than or equal to the median of the sample.

[21]See Carletti and Hartmann (2003) for a review of the literature.

for banks to take on excessive risk as a way to increase their returns (Berger, Klapper, and Turk-Ariss 2009).

We measure market power in the banking system with the Lerner index.[22] Heightened CBI can discourage risky behavior caused by high market power, as the central bank authorities can evade capture by financial participants and strengthen the supervisory functions of the central bank.

HYPOTHESIS 5. *Rigid exchange rate regimes positively contribute to systemic risk, but a higher level of CBI alleviates the effect.*

Rigid exchange rates are associated with greater foreign currency borrowing that exposes the economy to systemic risk (Dell'Ariccia, Laeven, and Marquez 2020). An independent monetary policy authority may be able to avoid this problem, however, through mitigating the effects of foreign currency borrowing and mitigating the effects from systemic risk contagion.

For Hypothesis 1 (results are presented in Table 4), the standalone coefficients of CBI as well as of FSM variables are negative (i.e., restraining, as expected, banks' systemic risk contribution), but the coefficients of their interactions are positive, indicating trade-offs between CBI and FSM. It also points out that, in terms of channels for CBI to affect systemic risk, the CBI has helped address systemic risk rather through monetary policy[23,24] or involvement in prudential supervision than through an explicit financial stability mandate. A closer look at the four corner solutions resulting from the coefficients of CBI and FSM (Table 4)—given that the CBI variable has a maximum value of 1 and a minimum of 0 and the FSM variable has a value of 1 when a FSM exists and 0 otherwise—reveals that the largest overall effects are obtained from combining the highest possible central bank independence with no financial stability

[22]The Lerner index is defined as the difference between output prices and marginal costs relative to prices.

[23]See Adrian and Liang (2018) and Lamers et al. (2019) for channels through which monetary policy can affect financial stability.

[24]Levieuge, Lucotte, and Pradines-Jobet (2019) also find that differences in monetary policy preferences—relative preferences of central banks for the inflation stabilization—explain cross-country differences in banking vulnerabilities. Namely, if central banks were more preoccupied with output stabilization, they would focus more on financial stability objectives.

mandate.[25] This result is in line with the conclusion of Ueda and Valencia (2014), who find that having both price and financial stability mandates does not deliver social optimum due to a time-inconsistency problem.

A second-best solution points towards a less central bank independence with a financial stability mandate. Svensson (2013) considers that it may make sense to assign the objective of financial stability to the central bank, if the central bank is given control of the appropriate supervisory, regulatory, and crisis-management instruments. Bringing monetary and macroprudential policies under one central bank roof will tend to solve possible coordination problems that may arise from their interaction, but it may lead to incentive problems if failure of one policy domain affects the other policy domain (Smets 2014).

A caveat is in order here: while some central banks had financial stability mandates (albeit in most of the cases, secondary to the price stability mandate) before the financial crisis, their weight in the central banks' decisions and preferences has likely evolved after the crisis.[26] Similarly to Adrian and Liang (2018), our results emphasize that more research is needed to evaluate the efficacy of monetary and macroprudential policies framework to address systemic risk and to mitigate the consequences on the real economy.

Further, we do not find a significant impact on systemic risk measures from the proxies used for quality of microprudential supervision or quality of macroprudential supervision. Going forward, institutional arrangements for cooperation with other financial stability agencies for the implementation of macroprudential policies are needed and the governance of the current ones strengthened. Edge and Liang (2019) evaluated institutional structures and practices of macroprudential authorities in 58 countries as they continued to develop their frameworks and found that while most countries have established financial stability committees, many of these lack effectiveness.

---

[25] We would like to thank an anonymous referee for suggesting the corner solution analysis.

[26] Central banks have started to communicate financial (in)stability issues more intensively (Horváth and Vaško 2016), but the degree to which financial stability considerations are taken into account in the monetary policy decision differs substantially across central banks (Friedrich, Hess, and Cunningham 2019).

Table 4. Interaction Regression Results: Financial Stability Mandate

Dependent: ΔCoVaR	(1)	(2)	(3)	(4)	(5)
Fixed-Effects Parameters					
CBI Index (t–1)	−0.955***	−0.741***	−0.558***	−0.578***	−0.541***
	(0.160)	(0.163)	(0.146)	(0.164)	(0.145)
FS Mandate/Objective (t–1)	−0.655***				
	(0.108)				
FS Mandate/Objective (t–1) × CBI (t–1)	1.058***				
	(0.191)				
FS Report (t–1)		−0.269***			
		(0.064)			
FS Report (t–1) × CBI (t–1)		0.484***			
		(0.111)			
CB Role in MaPru Committee (t–1)			−0.454***		
			(0.075)		
CB Role in MaPru Committee (t–1) × CBI (t–1)			0.537***		
			(0.114)		
High MaPru Index (t–1)				−0.114	
				(0.089)	
High MaPru Index (t–1) × CBI (t–1)				0.104	
				(0.027)	
High-Quality MiPru Supervision Index (t–1)					−0.080
					(0.075)
High-Quality MiPru Supervision Index (t–1) × CBI (t–1)					0.026
					(0.123)
Size (t–1)	0.032	0.026	0.051**	0.037*	0.108***
	(0.021)	(0.021)	(0.020)	(0.020)	(0.020)

(continued)

Table 4. (Continued)

Dependent: ΔCoVaR	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Credit Risk Ratio (t–1)	0.442	0.308	0.483	0.382	0.293
	(0.314)	(0.316)	(0.313)	(0.315)	(0.283)
Profitability (t–1)	1.173	1.194	1.384	1.563	0.811
	(1.232)	(1.238)	(1.232)	(1.242)	(1.125)
Capitalization (t–1)	−0.931**	−0.950**	−0.970**	−0.920*	−0.333
	(0.440)	(0.441)	(0.440)	(0.441)	(0.404)
Funding Structure (t–1)	−0.405***	−0.455***	−0.362***	−0.446***	−0.195*
	(0.130)	(0.128)	(0.129)	(0.129)	(0.118)
Real GDP Growth (t–1)	−0.659	−0.940**	−1.051**	−0.932**	−0.752*
	(0.459)	(0.460)	(0.459)	(0.464)	(0.414)
Inflation (t–1)	0.001	0.002	0.000	0.001	−0.003
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Bank Concentration (t–1)	−0.002**	−0.002**	−0.002**	−0.003***	−0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Financial Intermediation (t–1)	0.001*	0.001**	0.001	0.001**	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)
CBIS Index (t–1)	−0.092***	−0.075***	−0.062***	−0.078***	−0.061***
	(0.021)	(0.020)	(0.020)	(0.021)	(0.018)
Constant	1.039*	1.011*	0.297	0.769	−0.779
	(0.556)	(0.548)	(0.547)	(0.544)	(0.521)
Observations	3,313	3,313	3,313	3,313	3,181
Countries	40	40	40	40	40
Banks	322	322	322	322	322
LR Test Chi-Square	2,942.613***	2,865.342***	2,921.208***	2,867.126***	3,356.458***

Note: This table reports the results for the base model described in Equation (2). The dependent variable is ΔCoVaR, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively. To conserve space, we suppressed the output for random-effects parameters.

Regarding institutional development (Hypothesis 2), results presented in Table 5 show that a low level of financial freedom increases banks' contribution to systemic risk, with this effect being ameliorated by an increase in CBI. We also see that countries with a higher-than-median level of the financial markets index that captures the development of financial markets (depth, access, and efficiency) are prone to an enhanced contribution to systemic risk. Our results are in line with Bostandzic and Weiß (2018), where their results reveal that the global importance of a country's stock market increases systemic risk. According to our results, the development in a country's material living standards is not associated with systemic risk. In line with the results of previous studies,[27] results from Models 4 and 5 show that financial institutions development and the overall financial development indices are not associated with systemic risk and neither augment nor mitigate the effect of CBI on systemic risk.

For Hypothesis 3, as anticipated, the sign of the interaction coefficient *Crisis* × *CBI (t–1)* is positive and significant in the case of the systemic interconnectedness measure (Table 6, Model 1). Thus, when crisis hits, a highly independent central bank could exacerbate delays in implementation of crisis measures when coordination with other institutions is involved. This suggests that there is need for a reassessment of the cooperation and collaboration between policymakers, especially in the context of the progress in institutional governance in the last two decades. Credibility and accountability of all players is pivotal.

Furthermore, if a banking sector is characterized by a high market power, the effect is an increase of systemic risk contribution of banks. This negative effect is diminished if the central bank acts independently without any external interference. Regarding the effect of the exchange rate regime and CBI influence on it, we did not find backing for our hypothesis, as the corresponding coefficients are insignificant.

[27]See, e.g., Brunnermeier and Oehmke (2012), who reveal that crises have occurred at all stages of financial system development: developed financial systems as well as emerging economies and developing financial systems.

Table 5. Interaction Regression Results: Institutional Development

Dependent: ΔCoVaR	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Fixed-Effects Parameters					
CBI Index (t–1)	−0.531**	−0.427***	−0.428***	−0.641***	−0.638***
	(0.258)	(0.165)	(0.163)	(0.160)	(0.159)
Low Real GDP/Capita (t–1)	0.027				
	(0.141)				
Low Real GDP/Capita (t–1) × CBI (t–1)	−0.069				
	(0.255)				
Low Financial Freedom Index (t–1)		0.322***			
		(0.097)			
Low Financial Freedom Index (t–1) × CBI (t–1)		−0.575***			
		(0.147)			
High Financial Markets Index (t–1)			0.343***		
			(0.092)		
High Financial Markets Index (t–1) × CBI (t–1)			−0.317*		
			(0.163)		
High Financial Institutions Index (t–1)				−0.021	
				(0.307)	
High Financial Institutions Index (t–1) × CBI (t–1)				0.183	
				(0.375)	
High Financial Development Index (t–1)					−0.132
					(0.118)
High Financial Development Index (t–1) × CBI (t–1)					0.326
					(0.200)
Size (t–1)	0.034*	0.035*	0.058***	0.034	0.033
	(0.021)	(0.021)	(0.020)	(0.020)	(0.021)

(*continued*)

Table 5. (Continued)

Dependent: ΔCoVaR	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Credit Risk Ratio (t–1)	0.403	0.499	0.582*	0.338	0.395
	(0.316)	(0.316)	(0.315)	(0.318)	(0.315)
Profitability (t–1)	1.604	1.726	1.401	1.530	1.637
	(1.238)	(1.236)	(1.232)	(1.237)	(1.237)
Capitalization (t–1)	−0.902**	−0.974**	−0.742*	−0.912**	−0.870**
	(0.442)	(0.441)	(0.441)	(0.441)	(0.442)
Funding Structure (t–1)	−0.441***	−0.445***	−0.404***	−0.440***	−0.447***
	(0.129)	(0.129)	(0.128)	(0.129)	(0.129)
Real GDP Growth (t–1)	−0.843*	−0.825*	−0.975**	−0.844*	−0.862*
	(0.461)	(0.460)	(0.459)	(0.461)	(0.462)
Inflation (t–1)	0.001	0.002	0.000	0.001	0.002
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Bank Concentration (t–1)	−0.003***	−0.003***	−0.003***	−0.002***	−0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Financial Intermediation (t–1)	0.001**	0.001**	0.001**	0.001*	0.001**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CBIS Index (t–1)	−0.079***	−0.076***	−0.069***	−0.079***	−0.078***
	(0.020)	(0.020)	(0.020)	(0.020)	(0.020)
Constant	0.776	0.687	0.099	0.818	0.837
	(0.551)	(0.553)	(0.547)	(0.546)	(0.549)
Observations	3,313	3,131	3,313	3,313	3,313
Countries	40	40	40	40	40
Banks	322	322	322	322	322
LR Test Chi-Square	2,882.915***	2,918.253***	2,895.622***	2,898.157***	2,877.445***

Note: This table reports the results for the base model described in Equation (2). The dependent variable is ΔCoVaR, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively. For the sake of conserving space, we do not present the output for random-effects parameters.

Table 6. Interaction Regression Results: Other Interactions

Dependent: ΔCoVaR	(1)	(2)	(3)
Fixed-Effect Parameters			
CBI Index (t–1)	−0.742***	−0.492***	−0.616***
	(0.160)	(0.163)	(0.146)
Crisis	0.135**		
	(0.067)		
Crisis × CBI (t–1)	0.336***		
	(0.079)		
High Lerner Index (t–1)		0.226***	
		(0.067)	
High Lerner Index (t–1) × CBI (t–1)		−0.313***	
		(0.114)	
Rigid Exchange Rate (t–1)			0.036
			(0.092)
Rigid Exchange Rate (t–1) × CBI (t–1)			−0.196
			(0.125)
Size (t–1)	0.031	0.036*	0.092***
	(0.021)	(0.021)	(0.020)
Credit Risk Ratio (t–1)	0.366	0.338	0.488*
	(0.314)	(0.322)	(0.293)
Profitability (t–1)	1.075	1.219	0.943
	(1.240)	(1.321)	(1.162)
Capitalization (t–1)	−0.873**	−0.904**	−0.475
	(0.441)	(0.450)	(0.416)
Funding Structure (t–1)	−0.471***	−0.507***	−0.329***
	(0.129)	(0.137)	(0.120)
Real GDP Growth (t–1)	−0.874*	−1.026**	−1.014**
	(0.459)	(0.470)	(0.421)
Inflation (t–1)	0.003	0.001	−0.005
	(0.004)	(0.004)	(0.004)
Bank Concentration (t–1)	−0.002**	−0.003***	−0.002***
	(0.001)	(0.001)	(0.001)
Financial Intermediation (t–1)	0.001*	0.001**	0.003***
	(0.001)	(0.001)	(0.001)
CBIS Index (t–1)	−0.084***	−0.081***	−0.065***
	(0.020)	(0.021)	(0.018)
Constant	0.958*	0.803	−0.377
	(0.547)	(0.560)	(0.542)
Observations	3,313	3,244	2,999
Countries	40	40	40
Banks	322	322	322
LR Test Chi-Square	2,929.444***	2,825.339***	3,200.578***

Note: This table reports the results for the model described in Equation (2). The dependent variable is ΔCoVaR, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively. For the sake of conserving space, we do not present the output for random-effects parameters.

3.4 Robustness Assessment

3.4.1 Robustness Assessment Using Different Estimation Techniques

To test the consistency of the results, we run alternative estimation models. First, we reestimate the model described in Equation (1) fitting a restricted or residual maximum likelihood estimator (REML). Unlike ML, REML portions the likelihood function into two parts, one independent from the fixed effects (Corbeil and Searle 1976). The maximization of this part gives the REML.

Second, we employ the fixed-effects estimator using both bank and year fixed effects to capture any unobserved heterogeneity across banks and the influence of aggregate time-series trends. Third, to account for potential endogeneity steaming from amendments to CBI as a result of financial crisis or further financial stability mandate being added to central banks' responsibilities, we estimate a dynamic panel model using the System GMM estimator.[28]

Fourth, we use the bias-corrected least square dummy variable (LSDVC) estimator proposed by Kiviet (1995) and subsequently Bun and Kiviet (2003), and extended to an unbalanced panel setting by Bruno (2005). It was shown in Monte Carlo simulations that the LSDVC outperforms the IV-GMM estimators in terms of bias and root mean squared error.

The findings are displayed in Table 7. The negative and significant effect of central bank independence on systemic risk contribution holds across all four models, in the case of both static and dynamic models. The LR test in the case of HLM REML compares the estimated model and the standard OLS estimation, with the null hypothesis that there are no significant differences between the two models. The results favor the multi-level specification.

3.4.2 Robustness Assessment Using Different Proxies for Systemic Risk Contribution

Further, we use alternative proxies for systemic risk contribution. Following the approach of Berger, Roman, and Sedunov (2020), we compute the principal-component factor using factor analysis based

[28]We thank a reviewer for suggesting this.

on our two systemic risk indicators, NSRISK and ΔCoVaR. We call the new measure Systemic Factor2. Employing factor analysis to construct new indicators of systemic risk, we synthesize the main information conveyed by NSRISK and ΔCoVaR. Additionally, we employ the same technique and compute Systemic Factor3, which is based on NSRISK, ΔCoVaR, and the Systemic Expected Shortfall (SES). According to Acharya et al. (2017), SES denotes a firm's "propensity to be undercapitalized when the system as a whole is undercapitalized," and it is a function of two variables: Marginal Expected Shortfall (MES) and Leverage (LVG).[29]

The results for Systemic Factor2 and Systemic Factor3 are shown in Table 8. We obtain the same negative and strongly significant relationship between this measure of systemic relevance and central bank independence, which is consistent with the main findings. Concerning control variables, *credit risk ratio, inflation* (Systemic Factor3), and *financial intermediation* amplify banks' systemic relevance, whereas *profitability* (Systemic Factor3), better *capitalization,* a funding structure based on deposits, *economic growth*, and the *central bank involvement in supervision* index reduce banks' contribution to systemwide distress. Thus, assigning supervisory responsibilities to the central bank is beneficial for stability of the banking system and financial system as a whole. Doumpos, Gaganis, and Pasiouras (2015) reach similar conclusion in terms of bank soundness.

Finally, we test whether the findings are driven by sample selection. First, we exclude from the analysis (a) the countries with the highest number of banks (the United States and Japan), (b) the countries with no more than three banks, and (c) both groups of countries. A detailed list with the number of banks by country is given in Table A.1 from the appendix. Then, we look at whether the effect of CBI and the control variables differ substantially before and during/after the global financial crisis: (d) for the 2001–07 period and (e) for the 2008–14 period. The results are shown in Table 9. For the samples in (a), (b), and (c), the findings are in line with those from the benchmark model (Table 1). Regarding the estimations for sub-periods, the sign for the CBI's coefficients holds for

[29]A description of these variables and the computational methodological is provided in Table A.2 in the appendix.

Table 7. Robustness Analysis Using Different Estimation Techniques

Dependent: ΔCoVaR	(1) HLM REML	(2) FE	(3) System GMM	(4) LSDVC
CBI Index (t–1)	−0.580***	−0.716***	−0.460***	−0.314*
	(0.158)	(0.225)	(0.102)	(0.177)
Size (t–1)	0.027	−0.071	0.094***	0.057*
	(0.021)	(0.091)	(0.035)	(0.033)
Credit Risk Ratio (t–1)	0.383	0.554	0.023	0.326
	(0.317)	(0.950)	(0.344)	(0.306)
Profitability (t–1)	1.473	1.452	0.860	−0.453
	(1.245)	(1.764)	(1.067)	(1.203)
Capitalization (t–1)	−1.074**	−1.046	−0.099	−0.321
	(0.443)	(1.003)	(0.399)	(0.437)
Funding Structure (t–1)	−0.443***	−0.669**	−0.180	−0.053
	(0.130)	(0.277)	(0.119)	(0.130)
Real GDP Growth (t–1)	−0.830*	−0.771	−0.204	−0.289
	(0.464)	(0.832)	(0.392)	(0.404)
Inflation (t–1)	0.001	−0.000	−0.002	−0.002
	(0.004)	(0.010)	(0.004)	(0.003)
Bank Concentration (t–1)	−0.003***	−0.003	−0.002**	−0.000
	(0.001)	(0.002)	(0.001)	(0.001)
Financial Intermediation (t–1)	0.001**	0.001	0.001**	0.001**
	(0.001)	(0.002)	(0.001)	(0.001)
CBIS Index (t–1)	−0.078***	−0.072***	0.001	−0.042**
	(0.020)	(0.025)	(0.013)	(0.021)
ΔCoVaR (t–1)			0.914***	0.692***
			(0.100)	(0.018)
ΔCoVaR (t–2)			−0.628***	
			(0.075)	
Constant	0.985*	4.132*		
	(0.549)	(2.202)		
Observations	3,327	3,327	3,327	3,327
Countries	40	40	40	40
Banks	323	323	323	323
LR Test Chi-Square	2,933.362***			
R-Squared (Within)		0.328		
AR(1) Test			−6.107***	
AR(2) Test			0.406	
Hansen J Statistic			0.018	
No. of Instruments			27	

(*continued*)

Table 7. (Continued)

Note: This table reports the results using different estimation techniques. The dependent variable is ΔCoVaR, defined in Table A.2 in the appendix. The HML REML model is estimated using the restricted maximum likelihood estimation. The FE model is estimated using both bank and year fixed effects. The System GMM model follows the approach of Blundell and Bond (1998) and is estimated using the finite-sample correction to the two-step covariance matrix derived by Windmeijer (2005). To deal with serial correlation, we added the second lag of the dependent variable. The LSDVC model is the bias-corrected least square dummy variable developed by Kiviet (1995) and adopted to unbalanced panels by Bruno (2005), being initialized by the Blundell-Bond estimator. The LR test compares the estimated model with the standard OLS estimation with the null hypothesis that there are no significant differences between the two models. AR(1) and AR(2) are the Arellano-Bond test for first-order and second-order correlation, respectively, whereas the Hansen J statistic tests the validity of the overidentification restrictions with the null hypothesis that overidentification restrictions are valid. Standard errors are in parentheses for HLM REML. Cluster-robust standard errors at the country level are in parentheses for FE. Corrected standard errors are in parentheses for System GMM. Bootstrap standard errors are in parentheses based on 100 replications for LSDVC. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively. For the sake of conserving space, we do not present the output for random-effects parameters for HLM REML.

both periods, but the significance is preserved only for the second period. While this can lend support for a more important role of CBI during/after the crisis, different sample sizes—the estimation for the second period includes four additional countries, with 22 additional banks—likely affects this as well.

Table 8. Robustness Analysis: Different Systemic Risk Measures

	(1)	(2)
Dependent: ΔCoVaR	**Systemic Factor2**	**Systemic Factor3**
Fixed-Effects Parameters		
CBI Index (t–1)	−0.996***	−2.544***
	(0.210)	(0.443)
Size (t–1)	−0.044*	−0.130**
	(0.026)	(0.052)
Credit Risk Ratio (t–1)	1.327***	2.831***
	(0.419)	(0.873)
Profitability (t–1)	−1.586	−8.216**
	(1.587)	(3.266)
Capitalization (t–1)	−3.896***	-11.233***
	(0.565)	(1.177)
Funding Structure (t–1)	−1.026***	−2.461***
	(0.165)	(0.343)
Real GDP Growth (t–1)	−1.416**	−2.674**
	(0.595)	(1.230)
Inflation (t–1)	0.008	0.022**
	(0.005)	(0.011)
Bank Concentration (t–1)	0.000	0.003
	(0.001)	(0.002)
Financial Intermediation (t–1)	0.007***	0.021***
	(0.001)	(0.002)
CBIS Index (t–1)	−0.072***	−0.108*
	(0.027)	(0.056)
Constant	0.700	0.486
	(0.690)	(1.431)
Random-Effects Parameters		
Country-Level Variance	−0.420***	0.536***
	(0.147)	(0.133)
Bank-Level Variance	−0.425***	0.253***
	(0.046)	(0.047)
Residual Variance	−0.678***	0.040***
	(0.013)	(0.013)
Observations	3,284	3,248
Countries	40	40
Banks	323	323
LR Test Chi-Square	2,541.686***	2,475.609***

Note: This table reports the results for alternative measures of systemic risk. The dependent variables are Systemic Factor2 and Systemic Factor3, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

Table 9. Robustness Analysis Using Different Sample Structures

	(1)	(2)	(3)	(4)	(5)
Dependent: ΔCoVaR	**U.S. and Japan Excluded**	**No Countries with Fewer than Three Banks**	**(1) + (2)**	**Pre-crisis**	**Crisis/ Post-crisis**
Fixed-Effects Parameters					
CBI Index (t–1)	-0.596^{***}	-0.570^{***}	-0.577^{***}	−0.465	-0.783^{***}
	(0.146)	(0.161)	(0.149)	(0.292)	(0.237)
Size (t–1)	0.131^{***}	0.029	0.137^{***}	0.097^{***}	-0.288^{***}
	(0.025)	(0.021)	(0.026)	(0.024)	(0.027)
Credit Risk Ratio (t–1)	−0.148	0.347	−0.201	-1.040^{*}	-1.697^{***}
	(0.321)	(0.319)	(0.322)	(0.578)	(0.490)
Profitability (t–1)	2.284^{*}	1.939	3.223^{**}	2.518	1.579
	(1.311)	(1.253)	(1.316)	(2.225)	(1.530)
Capitalization (t–1)	0.383	-1.161^{***}	0.292	1.271	-4.381^{***}
	(0.498)	(0.447)	(0.503)	(0.810)	(0.551)
Funding Structure (t–1)	−0.199	-0.416^{***}	−0.130	0.213	-1.508^{***}
	(0.135)	(0.132)	(0.138)	(0.212)	(0.161)
Real GDP Growth (t–1)	-0.913^{*}	-0.950^{**}	-0.963^{**}	-5.875^{***}	0.750^{*}
	(0.470)	(0.476)	(0.483)	(0.861)	(0.300)
Inflation (t–1)	−0.003	0.002	−0.002	0.002	0.005
	(0.004)	(0.004)	(0.004)	(0.008)	(0.004)
Bank Concentration (t–1)	-0.002^{*}	-0.003^{***}	-0.001^{*}	−0.002	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Financial Intermediation (t–1)	0.003^{***}	0.001^{***}	0.003^{***}	-0.005^{***}	-0.006^{***}
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CBIS Index (t–1)	-0.067^{***}	-0.084^{***}	-0.069^{***}	-0.162^{**}	-0.145^{***}
	(0.019)	(0.021)	(0.019)	(0.064)	(0.019)
Constant	-1.490^{**}	0.922^{*}	-1.628^{**}	−0.011	11.199^{***}
	(0.646)	(0.555)	(0.660)	(0.699)	(0.722)

(*continued*)

Table 9. (Continued)

	(1)	(2)	(3)	(4)	(5)
Dependent: ΔCoVaR	**U.S. and Japan Excluded**	**No Countries with Fewer than Three Banks**	**(1) + (2)**	**Pre-crisis**	**Crisis/ Post-crisis**
Random-Effects Parameters					
Country-Level Variance	−1.250***	−1.083***	−1.267***	−0.841***	0.037
	(0.216)	(0.203)	(0.221)	(0.195)	(0.132)
Bank-Level Variance	−0.552***	−0.535***	−0.559***	−0.754***	−0.261***
	(0.055)	(0.045)	(0.056)	(0.055)	(0.049)
Residual Variance	−0.995***	−0.916***	−1.002***	−0.767***	−1.203***
	(0.016)	(0.013)	(0.017)	(0.021)	(0.019)
Observations	2,080	3,201	1,954	1,490	1,837
Countries	38	34	32	36	40
Banks	224	310	211	280	320
LR Test Chi-Square	1,947.811***	2,787.773***	1,818.790***	677.442***	2,255.892***

Note: This table reports the results for different sample structures. The dependent variable is ΔCoVaR, defined in Table A.2 in the appendix. The HML model is estimated using the maximum likelihood estimation. The LR test compares the estimated model with the standard OLS regression, and the null hypothesis is that there are no significant differences between the two models. Standard errors in parentheses. ***, **, and * denote statistical significance at the 1 percent, 5 percent, and 10 percent level, respectively.

4. Conclusion

The agreement around the concept of central bank independence has lessened in the wake of the global financial crisis of 2007–09. This shift reflects an increase in the range of powers central bank have acquired, with some of these powers involving coordination with fiscal policymaking. Some evidence of distributional effects across different segments of population resulting from unconventional monetary policy has increased calls for reining in central bank independence. However, a core issue is how the financial stability that has been fastened stronger than before to central banks in many countries relates to the central bank independence.

We find a robust, negative, and significant impact of central bank independence on the contribution of banks to systemic risk, as well as a similar impact of central bank independence on stand-alone bank risk. These results lend support for central bank independence, as it helps banks reduce the risk they pose to the banking system as a whole as well as the risk individual banks face. In parallel, we find that an increase in CBI can ameliorate the effects of environments characterized by low level of financial freedom or high market power that, by themselves, enhance the systemic risk contribution of banks. However, the results also show trade-offs between CBI and central banks having financial stability mandates and that a heightened CBI can exacerbate the effect of a crisis on the contribution of banks to systemic risk.

Therefore, preserving central bank independence is important for financial stability but an emphasis on coordinated interaction with governments is also needed, or more elegantly in the words of former Federal Reserve chief Ben Bernanke: "The general principle of CBI does not preclude coordination of central bank policies with other parts of the government in certain situations" (Bernanke 2017). Better governance for the financial stability institutional structures would facilitate such needed collaboration.

We confirm a significant effect on the measure of the systemic relevance of bank characteristics (size, credit risk ratio, capitalization, profitability, funding structure), banking-sector characteristics (concentration, level of financial intermediation), macroeconomic variables (GDP growth and inflation), and the degree of central bank involvement in microprudential supervision. The findings are robust for different estimation models, controlling for both bank and year fixed effects and potential endogeneity issues of central bank independence, and for different sample structures.

Appendix

Table A.1. Distribution of the Banks by Country

Country	Number of Banks	Percent	Cumulative Percent
Australia	5	1.55	1.55
Austria	5	1.55	3.10
Bahrain	6	1.86	4.95
Belgium	1	0.31	5.26
Brazil	4	1.24	6.50
Canada	8	2.48	8.98
Chile	6	1.86	10.84
China	7	2.17	13.00
Croatia	1	0.31	13.31
Denmark	5	1.55	14.86
Egypt, Arab Rep.	6	1.86	16.72
France	6	1.86	18.58
Germany	3	0.93	19.50
Indonesia	8	2.48	21.98
Israel	6	1.86	23.84
Italy	13	4.02	27.86
Japan	48	14.86	42.72
Jordan	9	2.79	45.51
Kuwait	7	2.17	47.68
Malaysia	8	2.48	50.15
Mexico	4	1.24	51.39
Morocco	3	0.93	52.32
Norway	3	0.93	53.25
Pakistan	8	2.48	55.73
Peru	4	1.24	56.97
Philippines	8	2.48	59.44
Poland	8	2.48	61.92
Portugal	2	0.62	62.54
Qatar	8	2.48	65.02
Singapore	3	0.93	65.94
South Africa	5	1.55	67.49
Spain	5	1.55	69.04
Sri Lanka	5	1.55	70.59
Sweden	4	1.24	71.83
Switzerland	14	4.33	76.16
Thailand	4	1.24	77.40
Turkey	9	2.79	80.19
United Arab Emirate	8	2.48	82.66
United Kingdom	5	1.55	84.21
United States	51	15.79	100.00
Total	323	100	

Table A.2. Description of Variables

Variable Name	Definition	Source
Dependent Variables (Bank Level):		
Delta-CoVaR (ΔCoVaR)	Bank i's yearly contribution to systemic risk as defined by Adrian and Brunnermeier (2016). It is measured as the difference of the Value at Risk (VaR) of the system's market value of total assets conditional on the distress of a particular bank (5 percent worst outcomes) and the VaR of the system's market value of total assets conditional on the median state of the bank (median outcomes). ΔCoVaR is estimated using the quantile regression method for an empirical specification where the system's market value of total assets is regressed on each bank's market value of total assets and on a set of market indices that captures the exposure of financial institutions to common factors. The common factors are (i) the daily return of MSCI World index; (ii) the volatility index (VIX); (iii) the daily real estate sector return (MSCI World Real Estate) in excess of the banking-sector return (MSCI World Banks); (iv) the change in the three-month T-bill rate; (v) the spread between three-month repo rate and three-month T-bill rate; (vi) the spread of change in 10-year bond yield and three-month T-bill rate; and (vii) the change in the spread of Moody's Baa corporate bond yield and 10-year bond yield. System is defined as the market value of total assets of the sample. The indicator is expressed as a positive number, higher values being associated with greater systemic importance.	Own Calculations
Normalized SRISK (NSRISK)	The loss of the bank i within a year conditional by the whole system being in distress (5 percent worst outcomes of the market capitalization) per unit of market capitalization. SRISK is determined using the GJR-GARCH method with two-steps quasi-maximum likelihood (QML) estimation as in Acharya, Engle, and Richardson (2012) and Brownlees and Engle (2017), and we divide it by bank i's market capitalization to get NSRISK. SRISK is expressed in USD as well as market capitalization. System is defined by the MSCI World Financials Index. Higher values are associated with greater systemic importance.	Own Calculations

(*continued*)

Table A.2. (Continued)

Variable Name	Definition	Source
Marginal Expected Shortfall (MES)	Yearly marginal expected shortfall, defined by Acharya et al. (2017) as the average return on an individual bank's stock on the days the MSCI World Financials Index experienced its 5 percent worst outcomes. Conditional volatilities of the equity returns are modeled using asymmetric GJR-GARCH models with two-steps quasi-maximum likelihood (QML) estimation, whereas time-varying conditional correlation is modeled using the dynamic conditional correlation (DCC) framework of Engle (2002). System is defined by the MSCI World Financials Index. The indicator is expressed as a positive number, higher values being associated with greater systemic importance.	Own Calculations
Exposure-ΔCoVaR (eΔCoVaR)	Bank *i*'s yearly exposure to systemic risk as defined by Adrian and Brunnermeier (2016). It is measured as the difference of the Value at Risk (VaR) of market value of total assets of a particular bank *i* conditional on the distress of the system (5 percent worst outcomes) and the VaR of the bank *i*'s value of total assets conditional on the median state of the system (median outcomes). eΔCoVaR is estimated using the quantile regression method for an empirical specification where the system's market value of total assets is regressed on each bank's market value of total assets and on a set of market indices that captures the exposure of financial institutions to common factors. The common factors are (i) the daily return of MSCI World index; (ii) the volatility index (VIX); (iii) the daily real estate sector return (MSCI World Real Estate) in excess of the banking-sector return (MSCI World Banks); (iv) the change in the three-month T-bill rate; (v) the spread between three-month repo rate and three-month T-bill rate; (vi) the spread of change in 10-year bond yield and three-month T-bill rate; and (vii) the change in the spread of Moody's Baa corporate bond yield and 10-year bond yield. System is defined as the market value of total assets of the sample. The indicator is expressed as a positive number, higher values being associated with greater systemic importance.	Own Calculations

(*continued*)

Table A.2. (Continued)

Variable Name	Definition	Source
Leverage (LVG, Market Leverage)	Market leverage computed as the ratio of the quasi-market value of assets divided by market value of common equity, where the quasi-market value of assets is book value of assets minus book value of common equity plus market value of common equity as in Acharya et al. (2017).	Own Calculations
Systemic Expected Shortfall (SES)	Bank propensity to be undercapitalized when the system as a whole is undercapitalized, which increases in its leverage, volatility, correlation, and tail dependence. SES is computed as in Acharya et al. (2017), based on MES and LVG for each bank i in year t: $\text{SES}_{i,t} = 0.02 - 0.15 \times \text{MES}_{i,t-1} - 0.04 \times \text{LVG}_{i,t-1}$. The indicator is expressed as a positive number, higher values being associated with greater systemic importance.	Own Calculations
Systemic Factor2	Principal-component factor computed using factor analysis based on ΔCoVaR and NSRISK similar to Berger, Roman, and Sedunov (2020). The indicator is expressed as a positive number, higher values being associated with greater systemic importance.	Own Calculations
Systemic Factor3	Principal-component factor computed using factor analysis based on ΔCoVaR, NSRISK, and SES similar to Berger, Roman, and Sedunov (2020). The indicator is expressed as a positive number, higher values being associated with greater systemic importance.	Own Calculations
Value at Risk (VaR)	The maximum possible loss as a percent of the total market equity that a bank could register for a given confidence level (95 percent). The loss is found in the left tail corresponding to 95 percent confidence level of the returns distribution function. The indicator is expressed as a positive number, higher values being associated with greater individual risk.	Own Calculations
Beta	Dynamic conditional beta computed using the dynamic conditional correlation (DCC) framework of Engle (2002) to capture the conditional co-movement between each bank and the market (MSCI World Financials Index), where the GJR-GARCH process is employed to account for the conditional heteroskedasticity.	Own Calculations

(continued)

Table A.2. (Continued)

Variable Name	Definition	Source
Data Used for Systemic Risk (Bank Level):		
Market Equity	Market Capitalization in U.S. Dollars	Datastream
Total Assets	Book Value of Total Assets	Worldscope
Book Equity	The Book Value of Common Equity	Worldscope
Market Assets	Total Assets × (Market Equity/Book Equity)	Own Calculations
MSCI World Financials Index (Market)	Log-Returns of MSCI World Financials Index	Datastream
Bank-Level Variables:		
Size	Natural Logarithm of Total Assets in U.S. Dollars	Worldscope
Credit Risk Ratio	Non-performing Loans/Total Loans	Worldscope
Profitability (ROA)	Net Income/Total Assets	Worldscope
Capitalization	Common Equity/Total Assets	Worldscope
Funding Structure	Total Deposits/Total Liabilities	Worldscope

(continued)

Table A.2. (Continued)

Variable Name	Definition	Source
Macro/Banking System Level Variables		
Central Bank Independence Index	Updated version of Cukierman, Webb, and Neyapti's (1992) index by Bodea and Hicks (2015). The index has four components that we use in our analysis relating to (i) appointment, dismissal, and term of office for the head of the central bank (personnel independence), (ii) the resolution of conflicts between the executive branch and the central bank (policy independence), (iii) the objectives of the central bank (central bank objectives), and (iv) the rules limiting lending to the government (financial independence). The indices range between 0 and 1, higher values being associated with greater independence.	Bodea and Hicks (2015) and Garriga (2016)
Real GDP Growth	Annual percentage growth rate of gross domestic product based on constant local currency. Aggregates are based on constant 2010 U.S. dollars.	WDI
Inflation	Inflation as measured by the change in consumer price index, reflecting the annual percentage change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed at specified intervals, such as yearly.	WDI
Bank Concentration	Assets of three largest banks as a share of total commercial banking assets. Total assets include total earning assets, cash and due from banks, foreclosed real estate, fixed assets, goodwill, other intangibles, current tax assets, deferred tax, discontinued operations, and other assets.	WDI
Financial Intermediation	Domestic credit provided by financial sector/GDP.	WDI
Central Bank Involvement in Supervision Index (CBIS Index)	An index that captures the roles of the central bank in supervising all, some, or none of the different financial-sector actors. CBIS index takes the maximum score of 6 in countries where all supervisory responsibilities are assigned to the central bank and the minimum score of 1 in countries where the central bank is not involved in supervision at all.	Masciandaro and Romelli (2018)

(*continued*)

Table A.2. (Continued)

Variable Name	Definition	Source
Variables Used in the Interaction Analyses:		
Financial Stability Mandate/Objective (FS Mandate/Objective)	Dummy variable that takes the value of 1 if the central bank has financial stability as de jure mandate/objective, and 0 otherwise.	Central Banks' Websites; IMF's FSAP Reports; CBLD; Edge and Liang (2019)
Financial Stability Report (FS Report)	Dummy variable that takes the value of 1 in the years the central bank published a stand-alone financial stability report/review, and 0 otherwise.	Central Banks' Websites; IMF's FSAP Reports; CBLD; Edge and Liang (2019)
Central Bank Role in Macruprudential Committee (CB Role in MaPru Committee)	Dummy variable that takes the value of 1 if the central bank has a primary or shared role in macroprudential committee, and 0 otherwise.	Central Banks' Websites; IMF's FSAP Reports; CBLD; Edge and Liang (2019)
High Macroprudential Index (High MaPru Index)	Dummy variable that takes the value of 1 if the macroprudential index is equal to or greater than the median of the sample, and 0 otherwise. The macroprudential index is developed by Cerutti, Claessens, and Laeven (2017) based on 12 dimensions: (i) loan-to-value ratio caps; (ii) debt-to-income ratio; (iii) dynamic loan loss provisioning; (iv) general countercyclical capital buffer; (v) leverage ratio; (vi) capital surcharges on systemically important financial institutions (SIFIs); (vii) limits on interbank exposures; (viii) concentration limits; (ix) limits of foreign currency loans; (x) foreign exchange and/or countercyclical reserve requirements; (xi) limits on domestic currency loans; and (xii) levy/tax on financial institutions. The index takes values from 0 to 12, higher values being associated with a greater use of macroprudential policies.	Cerutti, Claessens, and Laeven (2017)

(*continued*)

Table A.2. (Continued)

Variable Name	Definition	Source
High Quality of Microprudential Supervision (High Quality of MiPru Supervision)	Dummy variable that takes the value of 1 if the microprudential supervision index is greater than or equal to the median of the sample, and 0 otherwise. The microprudential index is constructed following the methodology of Anginer et al. (2014b) based on the bank regulation and supervision survey from the World Bank. The index takes values from 0 to 14, higher values being associated with high quality of microprudential supervision.	World Bank's Bank Regulation and Supervision Surveys; Anginer et al. (2014b)
Low Real GDP/Capita	Dummy variable that takes the value of 1 if the PPP GDP/capita in constant 2017 international $ is less than the median of the sample, and 0 otherwise.	WDI
Low Financial Freedom Index	Dummy variable that takes the value of 1 if the financial freedom index is less than the median of the sample, and 0 otherwise. The financial freedom index is a measure of banking efficiency and independence from government control and interference in the financial sector. It takes values from 0 to 100, higher values being associated with negligible government interference.	Heritage Foundation
High Financial Markets Index	Dummy variable that takes the value of 1 if the financial markets index is equal to or greater than the median of the sample, and 0 otherwise. The financial markets index is based on financial markets depth, access, and efficiency, and follows the methodology of Sahay et al. (2015). The index takes values from 0 to 1, higher values being associated with more developed financial markets.	Sahay et al. (2015)
High Financial Institutions Index	Dummy variable that takes the value of 1 if the financial institutions index is equal to or greater than the median of the sample, and 0 otherwise. The financial institutions index is based on financial institutions depth, access, and efficiency, and follows the methodology of Sahay et al. (2015). The index takes values from 0 to 1, higher values being associated with more developed financial institutions.	Sahay et al. (2015)

(continued)

Table A.2. (Continued)

Variable Name	Definition	Source
High Financial Development Index	Dummy variable that takes the value of 1 if the financial development index is equal to or greater than the median of the sample, and 0 otherwise. The financial development index is based on financial markets and institutions indices, and follows the methodology of Sahay et al. (2015). The index takes values from 0 to 1, higher values being associated with increased financial development.	Sahay et al. (2015)
Crisis	Dummy variable which takes the value of 1 if the period is between 2007 and 2013, and 0 otherwise.	Own Calculations
High Market Power	The values of Lerner index greater than or equal to the median of the sample. Lerner index is defined as the difference between output prices and marginal costs (relative to prices). An increase in the Lerner index indicates a deterioration of the competitive conduct of financial intermediaries.	WDI
Rigid Exchange Rate Regime	Dummy variable that takes the value of 0 if the exchange regime in a country is either floating or free floating, and 1 otherwise.	IMF

Note: CBLD stands for Central Bank Legislation Database; WDI stands for World Development Indicators; and IMF's PSAP stands for International Monetary Fund's Financial Sector Assessment Program.

Table A.3. Summary Statistics

	Mean	St. Dev.	p25	Median	p75	Min.	Max.	Obs.
ΔCoVaR	1.247	0.892	0.591	1.178	1.804	−2.39	5.484	3,327
NSRISK	23.350	87.948	−14.675	0.316	36.879	−70.019	2,841.164	3,284
CBI Index	0.565	0.194	0.472	0.475	0.775	0.173	0.954	3,293
Personnel Independence	0.553	0.159	0.438	0.582	0.707	0.063	0.832	2,936
CB Objectives	0.559	0.227	0.400	0.600	0.600	0.000	1.000	2,936
Policy Independence	0.549	0.328	0.268	0.668	0.750	0.000	1.000	2,936
Financial Independence	0.587	0.290	0.329	0.626	0.891	0.013	1.000	2,936
Size	24.204	1.716	23.148	24.011	25.06	18.568	29.011	3,327
Credit Risk Ratio	3.600	3.900	1.000	2.600	4.800	0.000	53.500	3,270
Profitability	1.300	1.400	0.500	1.200	1.800	−25.800	12.800	3,226
Capitalization	8.400	4.300	5.500	7.600	10.100	1.100	61.000	3,263
Funding Structure	74.900	19.300	63.800	79.900	90.900	0.000	100.400	3,327
Real GDP Growth	2.800	3.400	1.400	2.400	4.200	−5.700	26.200	3,327
Inflation	2.846	3.823	0.803	2.27	3.393	−4.863	54.4	3,327
Bank Concentration	55.41	21.283	36.97	46.319	74.84	23.113	100	3,318
Financial Intermediation	165.619	90.878	85.909	156.385	227.188	15.171	346.489	3,321
CBIS Index	2.009	1.109	1.000	2.000	3.000	1.000	6.000	3,105

Note: These figures correspond to the actual number of observations that entered the estimation model. Statistics for control variables are based on ΔCoVaR estimation with CBI index as the main explanatory variable. A complete description of variables is given in Table A.2 from the appendix.

Table A.4. Correlation Matrix of the Regressors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) CBI Index	1.000														
(2) Personnel Indep.	0.189*	1.000													
(3) CB Objectives	0.592*	0.218*	1.000												
(4) Policy Indep.	0.561*	0.358*	0.419*	1.000											
(5) Financial Indep.	0.722*	−0.137*	0.326*	0.275*	1.000										
(6) Size	0.098*	−0.000	−0.061*	−0.091*	0.086*	1.000									
(7) Credit Risk	−0.068*	0.094*	0.017	0.263*	−0.151*	−0.218*	1.000								
(8) Profitability	0.094*	−0.088*	0.137*	0.021	0.203*	−0.147*	−0.167*	1.000							
(9) Capitalization	−0.072*	−0.082*	−0.003	−0.071*	0.122*	−0.427*	0.061*	0.457*	1.000						
(10) Funding Structure	−0.307*	0.192*	0.101*	−0.145*	−0.464*	−0.390*	0.138*	−0.219*	0.062*	1.000					
(11) Real GDP Growth	−0.032*	−0.057*	0.074*	−0.048*	0.114*	−0.144*	0.017	0.325*	0.269*	0.030*	1.000				
(12) Inflation	0.069*	−0.078*	0.037*	0.168*	0.180*	−0.210*	0.089*	0.333*	0.248*	−0.119*	0.274*	1.000			
(13) Bank Concentration	0.063*	−0.092*	0.082*	0.186*	0.102*	−0.033*	0.094*	0.113*	−0.032*	−0.335*	0.215*	0.118*	1.000		
(14) Financial Intermediation	−0.304*	0.091*	−0.071*	−0.262*	−0.455*	0.211*	−0.149*	−0.432*	−0.348*	0.333*	−0.477*	−0.487*	−0.448*	1.000	
(15) CBIS Index	−0.105*	−0.217*	−0.239*	0.087*	0.176*	−0.145*	0.192*	0.093*	0.314*	−0.159*	0.220*	0.204*	0.185*	−0.470*	1.000

Note: * denotes statistical significance at the maximum level of significance of 10 percent. These figures correspond to the actual number of observations that entered the estimation model, based on ΔCoVaR as dependent variable and CBI index as the main explanatory variable in the case of control variables.

References

Acemoglu, D., S. Johnson, P. Querubin, and J. A. Robinson. 2008. "When Does Policy Reform Work? The Case of Central Bank Independence." NBER Working Paper No. 14033.

Acharya, V., R. Engle, and M. Richardson. 2012. "Capital Shortfall: A New Approach to Ranking and Regulating Systemic Risks." *American Economic Review* 102 (3): 59–64.

Acharya, V., L. Pedersen, T. Philippon, and M. Richardson. 2017. "Measuring Systemic Risk." *Review of Financial Studies* 30 (1): 2–47.

Adrian, T., and M. K. Brunnermeier. 2016. "CoVaR." *American Economic Review* 106 (7): 1705–41.

Adrian, T., and N. Liang. 2018. "Monetary Policy, Financial Conditions, and Financial Stability." *International Journal of Central Banking* 14 (1): 73–131.

Anginer, D., A. Demirgüç-Kunt, and M. Zhu. 2014a. "How Does Competition Affect Bank Systemic Risk?" *Journal of Financial Intermediation* 23 (1): 1–26.

———. 2014b. "How Does Deposit Insurance Affect Bank Risk? Evidence from the Recent Crisis." *Journal of Banking and Finance* 48 (November): 312–21.

Arnone, M., B. J. Laurens, J.-F. Segalotto, and M. Sommer. 2009. "Central Bank Autonomy: Lessons from Global Trends." *IMF Staff Papers* 56 (2): 263–96.

Balls, E., J. Howar, and A. Stansbury. 2018. "Central Bank Independence Revisited: After the Financial Crisis, What Should a Model Central Bank Look Like?" M-RCBG Associate Working Paper No. 87.

Beck, T., O. De Jonghe, and K. Mulier. 2017. "Bank Sectoral Concentration and (Systemic) Risk: Evidence from a Worldwide Sample of Banks." CEPR Discussion Paper No. 12009.

Beck, T., A. Demirgüç-Kunt, and R. Levine. 2006. "Bank Concentration, Competition, and Crises: First Results." *Journal of Banking and Finance* 30 (5): 1581–1603.

Benoit, S., G. Colletaz, C. Hurlin, and C. Pérignon. 2013. "A Theoretical and Empirical Comparison of Systemic Risk Measures." HEC Paris Research Paper No. FIN-2014–1030.

Berger, A. N., L. F. Klapper, and R. Turk-Ariss. 2009. "Bank Competition and Financial Stability." *Journal of Financial Services Research* 35 (2): 99–118.

Berger, A. N., R. A. Roman, and J. Sedunov. 2020. "Did TARP Reduce or Increase Systemic Risk? The Effects of Government Aid on Financial System Stability." *Journal of Financial Intermediation* 43 (July): Article 100810.

Berger, H., J. de Haan, and S. C. W. Eijffinger. 2001. "Central Bank Independence: An Update of Theory and Evidence." *Journal of Economic Surveys* 15 (1): 3–40.

Berger, W., and F. Kißmer. 2013. "Central Bank Independence and Financial Stability: A Tale of Perfect Harmony?" *European Journal of Political Economy* 31 (September): 109–18.

Bernanke, B. 2004. "The Great Moderation." Remarks at the meetings of the Eastern Economic Association, Washington, DC, February 20. https://www.federalreserve.gov/boarddocs/speeches/2004/20040220/.

———. 2017. "Monetary Policy in a New Era." Paper prepared for conference on Rethinking Macroeconomic Policy, Peterson Institute, Washington DC, October 12–13.

Bisias, D., M. Flood, W. Lo, and S. Valavanis. 2012. "A Survey of Systemic Risk Analytics." *Annual Review of Financial Economics* 4 (1): 255–96.

Blundell, R., and S. Bond. 1998. "Initial Conditions and Moment Restrictions in Dynamic Panel Data Models." *Journal of Econometrics* 87 (1): 115–43.

Bodea, C., and R. Hicks. 2015. "Price Stability and Central Bank Independence: Discipline, Credibility, and Democratic Institutions." *International Organization* 69 (1): 35–61.

Bolton, P., S. Cecchetti, J. P. Danthine, and X. Vives. 2019. *Sound at Last? Assessing a Decade of Financial Regulation.* No. 1, The Future of Banking Series. London: Centre for Economic Policy Research.

Bostandzic, D., and G. N. F. Weiß. 2018. "Why Do Some Banks Contribute More to Global Systemic Risk?" *Journal of Financial Intermediation* 35 (Part A): 17–40.

Boyd, J. H., and G. De Nicolo. 2005. "The Theory of Bank Risk Taking and Competition Revisited." *Journal of Finance* 60 (3): 1329–43.

Boyd, J. H., G. De Nicolo, and A. M. Jalal. 2006. "Bank Risk-taking and Competition Revisited: New Theory and New Evidence." IMF Working Paper No. 06/297.

Brei, M., L. Gambacorta, and G. von Peter. 2013. "Rescue Packages and Bank Lending." *Journal of Banking and Finance* 37 (2): 490–505.

Brownlees, C., and R. Engle. 2017. "SRISK: A Conditional Capital Shortfall Measure of Systemic Risk." *Review of Financial Studies* 30 (1): 48–79.

Broz, L. 2002. "Political System Transparency and Monetary Commitment Regimes." *International Organization* 56 (4): 861–87.

Brunnermeier, M. K., and M. Oehmke. 2012. "Bubbles, Financial Crises, and Systemic Risk." NBER Working Paper No. 18398.

Bruno, G. S. F. 2005. "Approximating the Bias of the LSDV Estimator for Dynamic Unbalanced Panel Data Models." *Economics Letters* 87 (3): 361–66.

Bun, M. J. G., and J. F. Kiviet. 2003. "On the Diminishing Returns of Higher-Order Terms in Asymptotic Expansions of Bias." *Economics Letters* 79 (2): 145–52.

Capie, F., and G. Wood. 2013. "Central Bank Independence: A Victim of the Crisis?" *Economic Affairs* 33 (3): 379–85.

Carletti, E., and P. Hartmann. 2003. "Competition and Financial Stability: What's Special about Banking?" In *Monetary History, Exchange Rates and Financial Markets: Essays in Honour of Charles Goodhart*, Vol. 2, ed. P. Mizen. Cheltenham: Edward Elgar.

Cerutti, E., S. Claessens, and L. Laeven. 2017. "The Use and Effectiveness of Macroprudential Policies: New Evidence." *Journal of Financial Stability* 28 (February): 203–24.

Cihak M. 2010. "Price Stability, Financial Stability, and Central Bank Independence." In *Central Banking After the Crisis*, Proceedings of the 38^{th} Economics Conference 2010, 45–55. Vienna: Oesterreichische Nationalbank.

Collard, F., H. Dellas, B. Diba, and O. Loisel. 2017. "Optimal Monetary and Prudential Policies." *American Economic Journal: Macroeconomics* 9 (1): 40–87.

Condon, C. 2019. "Central Bank Independence." Bloomberg, July 8.

Corbeil R. R., and S. R. Searle. 1976. "Restricted Maximum Likelihood (REML) Estimation of Variance Components in the Mixed Model." *Technometrics* 18 (1): 31–38.

Cornille, D., F. Rycx, and I. Tojerow. 2019. "Heterogeneous Effects of Credit Constraints on SMEs' Employment: Evidence from the European Sovereign Debt Crisis." *Journal of Financial Stability* 41 (April): 1–13.

Crowe, C., and E. E. Meade. 2007. "The Evolution of Central Bank Governance around the World." *Journal of Economic Perspectives* 21 (4): 69–90.

Cukierman, A. 2008. "Central Bank Independence and Monetary Policymaking Institutions — Past, Present and Future." *European Journal of Political Economy* 24 (4): 722–36.

Cukierman, A., S. B. Webb, and B. Neyapti. 1992. "Measuring the Independence of Central Banks and Its Effect on Policy Outcomes." *World Bank Economic Review* 6 (3): 353–98.

De Bandt, O., and P. Hartmann. 2000. "Systemic Risk: A Survey." ECB Working Paper No. 35.

De Haan, J., C. Bodea, R. Hicks, and S. Eijffinger. 2018. "Central Bank Independence Before and After the Crisis." *Comparative Economic Studies* 60 (2): 183–202.

De Haan, J., and S. C. Eijffinger. 2016. "The Politics of Central Bank Independence." DNB Working Paper No. 539.

De Haan, W., M. Ellison, E. Ilzetzki, M. McMahon, and R. Reis. 2017. "The Future of Central Bank Independence: Results of the CFM-CEPR Survey." VoxEU, January 10. https://voxeu.org/article/future-central-bank-independence.

Dell'Ariccia, G., L. Laeven, and R. Marquez. 2020. "Financial Frictions, Foreign Currency Borrowing, and Systemic Risk." Working Paper.

Diebold, F. X., and K. Yılmaz. 2014. "On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms." *Journal of Econometrics* 182 (1): 119–34.

Doumpos, M., C. Gaganis, and F. Pasiouras. 2015. "Central Bank Independence, Financial Supervision Structure and Bank Soundness: An Empirical Analysis around the Crisis." *Journal of Banking and Finance* 61 (Supplement 1): S69–S83.

Edge, R. M., and N. Liang. 2019. "New Financial Stability Governance Structures and Central Banks." Working Paper No. 50, Brookings Institution Hutchins Center.

Engle, R. 2002. "Dynamic Conditional Correlation." *Journal of Business and Economic Statistics* 20 (3): 339–50.

Farhi, E., and J. Tirole. 2012. "Collective Moral Hazard, Maturity Mismatch, and Systemic Bailouts." *American Economic Review* 102 (1): 60–93.

Fernández-Albertos, J. 2015. "The Politics of Central Bank Independence." *Annual Review of Political Science* 18: 217–37.

Förch, T., and U. Sunde. 2012. "Central Bank Independence and Stock Market Returns in Emerging Economies." *Economics Letters* 115 (1): 77–80.

Friedrich, C., K. Hess, and R. Cunningham. 2019. "Monetary Policy and Financial Stability: Cross-Country Evidence." *Journal of Money, Credit and Banking* 51 (2–3): 403–53.

García-Herrero, A., and P. Del Rio Lopez. 2003. "Financial Stability and the Design of Monetary Policy." Working Paper No. 0315, Banco de España.

Garriga, A. C. 2016. "Central Bank Independence in the World: A New Data Set." *International Interactions* 42 (5): 849–68.

Goodhart, C. 2011. "The Changing Role of Central Banks." *Financial History Review* 18 (2): 135–54.

Goodhart, C., and R. Lastra. 2018. "Populism and Central Bank Independence." *Open Economies Review* 29 (1): 49–68.

Greenspan, A. 2007. *The Age of Turbulence: Adventures in a New World.* New York: Penguin Press.

Haltom, R., and A. J. Weinberg. 2017. "Does the Fed Have a Financial Stability Mandate?" Economic Brief No. 17-06, Federal Reserve Bank of Richmond.

Hartley, H. O., and J. N. K. Rao. 1967. "Maximum-likelihood Estimation for the Mixed Analysis of Variance Model." *Biometrika* 54 (1–2): 93–108.

Horváth, R., and D. Vaško. 2016. "Central Bank Transparency and Financial Stability." *Journal of Financial Stability* 22 (February): 45–56.

Issing, O. 2018. "The Uncertain Future of Central Bank Independence." VoxEU, April 2. https://voxeu.org/article/uncertain-future-central-bank-independence.

Jordà, Ò., M. Schularick, and A. M. Taylor. 2013. "When Credit Bites Back." *Journal of Money, Credit and Banking* 45 (s2): 3–28.

Kayo, E. K., and H. Kimura. 2011. "Hierarchical Determinants of Capital Structure." *Journal of Banking and Finance* 35 (2): 358–71.

Keefer, P. 2001. "When Do Special Interests Run Rampant? Disentangling the Role of Elections, Incomplete Information and Checks and Balances in Banking Crises." Policy Research Working Paper No. 2543, World Bank.

Khan, A. H., H. A. Khan, and H. Dewan. 2013. "Central Bank Autonomy, Legal Institutions and Banking Crisis Incidence." *International Journal of Finance and Economics* 18 (1): 51–73.

Kiviet, J. F. 1995. "On Bias, Inconsistency, and Efficiency of Various Estimators in Dynamic Panel Data Models." *Journal of Econometrics* 68 (1): 53–78.

Klomp, J., and J. de Haan. 2009. "Central Bank Independence and Financial Instability." *Journal of Financial Stability* 5 (4): 321–38.

Koenker, R., and G. S. Bassett. 1978. "Regression Quantiles." *Econometrica* 46: 33–50.

Kuttner, K. N., and A. S. Posen. 2010. "Do Markets Care Who Chairs the Central Bank?" *Journal of Money, Credit and Banking* 42 (2–3): 347–71.

Laeven, L., L. Ratnovski, and H. Tong. 2016. "Bank Size, Capital, and Systemic Risk: Some International Evidence." *Journal of Banking and Finance* 69 (Supplement 1): S25–S34.

Laeven, L., and F. Valencia. 2020. "Systemic Banking Crises Database II." *IMF Economic Review* 68 (2): 307–61.

Lamers, M., F. Mergaerts, E. Meuleman, and R. Vander Vennet. 2019. "The Tradeoff between Monetary Policy and Bank Stability." *International Journal of Central Banking* 15 (2): 1–42.

Langfield, S., and M. Pagano. 2016. "Bank Bias in Europe: Effects on Systemic Risk and Growth." *Economic Policy* 31 (85): 51–106.

Levieuge, G., Y. Lucotte, and F. Pradines-Jobet. 2019. "Central Banks' Preferences and Banking Sector Vulnerability." *Journal of Financial Stability* 40 (February): 110–31.

Li, K., D. Griffin, H. Yue, and L. Zhao. 2013. "How Does Culture Influence Corporate Risk-taking?" *Journal of Corporate Finance* 23 (December): 1–22.

Machado, J. A. F., and J. M. C. Santos Silva. 2013. "Quantile Regression and Heteroskedasticity." Working Paper, University of Surrey. https://jmcss.som.surrey.ac.uk/JM_JSS.pdf.

Marcato, G., S. Milcheva, and C. Zheng. 2018. "Market Integration, Country Institutions and IPO Underpricing." *Journal of Corporate Finance* 53 (December): 87–105.

Masciandaro, D., and D. Romelli. 2015. "Ups and Downs of Central Bank Independence from the Great Inflation to the Great Recession: Theory, Institutions and Empirics." *Financial History Review* 22 (3): 259–89.

———. 2018. "Central Bankers as Supervisors: Do Crises Matter?" *European Journal of Political Economy* 52 (March): 120–140.

Melecky, M., and A. M. Podpiera. 2013. "Institutional Structures of Financial Sector Supervision, Their Drivers and Historical Benchmarks." *Journal of Financial Stability* 9 (3): 428–44.

———. 2015. "Placing Bank Supervision in the Central Bank. Implications for Financial Stability Based on Evidence from the Global Crisis." Policy Research Working Paper No. 7320, World Bank.

Mersch, Y. 2017. "Central Bank Independence Revisited." Keynote address at the "Symposium on Building the Financial System of the 21st Century: An Agenda for Europe and the United States," Frankfurt, March 30. https://www.ecb.europa.eu/press/key/date/2017/html/sp170330.en.html.

Mishkin, F. S. 2004. "Can Inflation Targeting Work in Emerging Market Countries?" NBER Working Paper No. 10646. https://www.nber.org/papers/w10646.

Moser, C., and A. Dreher. 2010. "Do Markets Care about Central Bank Governor Changes? Evidence from Emerging Markets." *Journal of Money, Credit and Banking* 42 (8): 1589–1612.

Mourouzidou-Damtsa, S., A. Milidonis, and K. Stathopoulos. 2019. "National Culture and Bank Risk-taking." *Journal of Financial Stability* 40 (February): 132–43.

Nistor, S., and S. Ongena. 2020. "The Impact of Policy Interventions on Systemic Risk across Banks." Research Paper No. 20-101, Swiss Finance Institute. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2580791.

Osiński, J., K. Seal, and L. Hoogduin. 2013. "Macroprudential and Microprudential Policies: Toward Cohabitation." IMF Discussion Note No. 13/05.

Papadamou, S., M. Sidiropoulos, and E. Spyromitros. 2017. "Does Central Bank Independence Affect Stock Market Volatility?" *Research in International Business and Finance* 42 (December): 855–64.

Patro, D., M. Qi, and X. Sun. 2013. "A Simple Indicator of Systemic Risk." *Journal of Financial Stability* 9 (1): 105–16.

Pistoresi, B., F. Salsano, and D. Ferrari. 2011. "Political Institutions and Central Bank Independence Revisited." *Applied Economics Letters* 18 (7): 679–82.

Quintyn, M., and M. Taylor. 2003. "Regulatory and Supervisory Independence and Financial Stability." *CESifo Economic Studies* 49 (2): 259–94.

Reinhart, C. M., and K. S. Rogoff. 2009. "The Aftermath of Financial Crises." *American Economic Review* 99 (2): 466–72.

———. 2011. "From Financial Crash to Debt Crisis." *American Economic Review* 101 (5): 1676–1706.

Sahay, R., M. Cihak, P. M. N'Diaye, A. Barajas, D. B. Ayala Pena, R. Bi, Y. Gao et al. 2015. "Rethinking Financial Deepening: Stability and Growth in Emerging." IMF Staff Discussion Note No. 15/08.

Samarakoon, L. P. 2017. "Contagion of the Eurozone Debt Crisis." *Journal of International Financial Markets, Institutions and Money* 49 (July): 115–28.

Shim, J. 2013. "Bank Capital Buffer and Portfolio Risk: The Influence of Business Cycle and Revenue Diversification." *Journal of Banking and Finance* 37 (3): 761–72.

Smets, F. 2014. "Financial Stability and Monetary Policy: How Closely Interlinked?" *International Journal of Central Banking* 10 (2): 263–300.

Svensson, L. E. O. 2013. "Some Lessons from Six Years of Practical Inflation Targeting." *Economic Review* (Sveriges Riksbank) 3: 29–80.

Toniolo, G., and E. N. White. 2015. "The Evolution of Financial Stability Mandate: From Origins to Its Present Day." NBER Working Paper No. 20844.

Ueda, K., and F. Valencia. 2014. "Central Bank Independence and Macro-prudential Regulation." *Economics Letters* 125 (2): 327–30.

van Essen, M., P.-J. Engelen, and M. Carney. 2013. "Does 'Good' Corporate Governance Help in a Crisis? The Impact of Country- and Firm-Level Governance Mechanisms in the European Financial Crisis." *Corporate Governance: An International Review* 21 (3): 201–24.

Weiß, G. N. F., D. Bostandzic, and S. Neumann. 2014. "What Factors Drive Systemic Risk during International Financial Crises?" *Journal of Banking and Finance* 41 (April): 78–96.

Windmeijer, F. 2005. "A Finite Sample Correction for the Variance of Linear Efficient Two-Step GMM Estimators." *Journal of Econometrics* 126 (1): 25–51.

Xu, T. T., K. Hu, and U. S. Das. 2019. "Bank Profitability and Financial Stability." IMF Working Paper No. 19/5.

Optimal Credit, Monetary, and Fiscal Policy under Occasional Financial Frictions and the Zero Lower Bound*

Shifu Jiang
Hong Kong Monetary Authority

I study optimal credit, monetary, and fiscal policy under commitment in a model where financial intermediaries face an occasionally binding financial constraint; the monetary authority faces a zero lower bound; and the fiscal authority faces a budget constraint. Financial and productivity shocks can generate a trade-off between inflation stability and financial stability, which is resolved in favor of the latter. As the ZLB prevents full-scale monetary easing and financial distress disrupts the transmission mechanism, monetary policy should be relatively tight in normal times for precautionary reasons. However, monetary policy should be eased in response to large productivity shocks regardless of the sign. The policy based on optimized simple rules features too-aggressive credit interventions and insufficient monetary easing relative to the Ramsey policy.

JEL Codes: E44, E52, E6, C61.

1. Introduction

New developments after the 2007–09 global financial crisis (GFC) induced central banks to rethink their monetary policy frameworks. For example, neutral interest rates have been falling globally for years, and this trend is expected to persist (Holston, Laubach, and

*I would like to thank participants at several seminars and conferences for helpful comments. Especially, I am grateful to Tom Holden for his help with the DynareOBC toolkit and to journal editors and anonymous referees for their insightful suggestions. I declare that I have no relevant or material financial interests that relate to the research described in this paper. The views expressed in this paper are mine and do not represent the views of the Hong Kong Monetary Authority. Author e-mail: sjiang@hkma.gov.hk.

Williams 2017). Thus, monetary policy is more likely to hit the zero lower bound (ZLB). In addition, financial shocks that disrupt financial intermediation (Ivashina and Scharfstein 2010) and possibly the transmission mechanism of monetary policy (Altavilla, Canova, and Ciccarelli 2016) have received much attention. Indeed, Schularick and Taylor (2012) conclude that the financial system not only amplifies macroeconomic shocks but is also an independent source of volatility, while Jermann and Quadrini (2012) find financial shocks to be an important driver of business cycles. To ease financial crunches, unconventional monetary policies such as quantitative easing (QE) have been made popular with the hope of reducing long-term interest rates, boosting lending, and stimulating real activity.[1] In this course, there are ongoing debates on how the current policy framework should evolve and if the policy toolkit should be expanded.

This paper tries to shed some new light on this topic from a specific angle. I study optimal credit, monetary, and fiscal policy under commitment (Ramsey policy) in a low interest rate environment with financial and macroeconomic disturbances. Credit policy is modeled as private asset purchases; monetary policy controls the nominal interest rate subject to the ZLB; and fiscal policy sets a labor tax subject to the government budget constraint. Despite a large literature on each of these policies (summarized in the next section), the normative aspect of the joint policy has not yet been fully understood. For example, credit policy may restore the functioning of financial markets on which the transmission mechanism of monetary policy depends. But the literature often only considers credit policy in a liquidity trap or, when credit policy is not available, debates whether monetary policy should respond to financial conditions (Curdia and Woodford 2010). On the fiscal side, many

[1] It is relatively well established that unconventional monetary policy reduces the long-term interest rates. See, among many others, Gagnon et al. (2011) and Krishnamurthy and Vissing-Jorgensen (2011) for the Federal Reserve's QE, and Joyce et al. (2011) and Christensen and Rudebusch (2012) for the Bank of England's QE. However, unconventional monetary policy may have insignificant or unintended real effects through a bank lending channel, as shown by Acharya et al. (2017) and Chakraborty, Goldstein, and MacKinlay (2017). Overall, it is widely believed that this kind of policy played a key role during the GFC; see Cahn, Matheron, and Sahuc (2017), Del Negro et al. (2017), Quint and Rabanal (2017), etc.

countries are left with high levels of public debt after the GFC (see, e.g., Oh and Reis 2012; Caruso, Reichlin, and Ricco 2018), which must be stabilized by either inflation or fiscal surpluses going forward. In this context, potential losses on the central bank's balance sheet can increase the fiscal burden and make it more difficult to raise interest rates when the time comes (Evans et al. 2015).

In studying these issues, I focus on the Ramsey policy because the ability to commit has become more relevant in recent years, thanks to improved communication and active forward guidance. Moreover, expectation management has been at the center of recent policy revisions[2] because, e.g., a flattened Phillips curve downplays the role of aggregate demand and emphasizes the role of inflation expectations in controlling inflation. Svensson (2019) argues that central banks can adopt a "forecast-targeting" strategy. Forecast targeting means that policy instruments are set such that the resulting forecasts of target variables, e.g., inflation, are desirable. With this strategy, forward guidance is the default when central banks publish the paths of policy instruments and the forecasts of target variables that justify the policy decision.

In this paper, I employ a simple New Keynesian model augmented with Gertler and Kiyotaki (2010) style financial frictions. Financial intermediaries (referred to as banks) face a financial constraint derived from an agency problem between banks and depositors. A key feature of this model is that the financial constraint depends on banks' future profitability, which can be affected by the entire path of policy instruments. The constraint is slack in normal times but binds endogenously in periods of financial distress, which can be triggered by a "Minsky moment." That is, agents in the economy suddenly realize that the leverage is too high. Such moments are captured by a financial shock that directly tightens the financial constraint.[3] When the constraint is binding, banks have difficulties

[2]For example, Bernanke (2017)'s temporary price-level targeting, Svensson (2019)'s average inflation targeting, and Reifschneider and Williams (2000)'s risk-management rule all are techniques to exploit expectations and have received much attention from central banks.

[3]Bordalo, Gennaioli, and Shleifer (2018) and, more generally, the literature of behavioral finance provide the microfoundation. López-Salido, Stein, and Zakrajŝek (2017) discuss how Minsky moments are complementary to financial frictions in understanding the role of credit risks in macroeconomic

rolling over their short-term debt, which leads to a collapse in asset prices and investment. The consequent deleveraging process continues to weigh on aggregate demand and inflation. Since the root of the problem is a disruption to financial intermediation, credit policy is designed to replace constrained intermediaries (banks) by an unconstrained intermediary (the government). Moreover, monetary policy can relax the financial constraint by lowering banks' real borrowing costs. Put differently, the lack of monetary easing due to the ZLB tightens the financial constraint. The ensuing widening of the credit spread (i.e., the premium in the expected return on capital over the risk-free interest rate) limits the benefits of monetary easing at the ZLB (e.g., through a commitment to future interest rates). The tax policy is helpful because it gives the government an extra margin to affect inflation. However, the government cannot fully stabilize inflation and the credit spread simultaneously even with all three policies. Thus, the model features a trade-off between inflation stability and financial stability.

My main findings are as follows. Relative to a laissez-faire equilibrium, the Ramsey equilibrium features a stochastic steady state with higher output and a remarkably stable credit spread. The government's incentive to stabilize the credit spread depends primarily on labor market efficiency in the steady state. In the Ramsey equilibrium where the steady-state labor tax rate is fixed exogenously, the optimal credit spread approaches zero quickly as the steady-state labor tax rate increases. Quantitatively, any realistic level of the steady-state labor tax rate ($\geq$10 percent) would imply virtually zero volatility of the credit spread. In this environment, banks are encouraged to choose a higher leverage level that is associated with greater risk of hitting the financial constraint. In turn, the central bank is required to hold a positive amount of private assets and set a lower nominal interest rate on average. However, when the ZLB is slack, the risk that both the financial constraint and the ZLB can bind together gives the central bank a precautionary incentive to keep the nominal interest rate relatively high. On the fiscal front, I do not find that the government budget is an important constraint on

dynamics. Similar financial shocks are also considered in, e.g., Dedola and Lombardo (2012); Eggertsson and Krugman (2012); Del Negro et al. (2017); and Perri and Quadrini (2018).

optimal policy, because the discounted sum of cash flows stemming from the government's asset purchases is small.[4]

Next, I try to understand how optimal policy responds to different shocks. A contractionary financial shock has a much larger effect on output than on inflation. As the traditional Taylor-type rule puts more weight on inflation than on output, the prescribed monetary policy is largely unresponsive. By contrast, the optimal monetary policy is more dovish by focusing on financial distress while inflation is allowed to rise modestly. A labor tax rebate is employed to help curb inflation. And the central bank should ramp up its asset purchase program if the financial shock is large enough to make the ZLB binding. My model also contains a total factor productivity (TFP) shock. An unexpected improvement in productivity should relax the financial constraint thanks to a higher rate of return on bank assets. However, it could also be damaging when a poor policy drives the economy into the liquidity trap in such a way that the shortfall in demand widens suddenly and the financial constraint binds. To escape from the spiral of Fisherian deflation, the key is to lower the real interest rate, which is needed to stimulate aggregate demand and relax the financial constraint. In other words, there is no trade-off between inflation stability and financial stability in this case. However, the trade-off is prominent under a negative TFP shock. On the one hand, inflation stability requires a tightening of monetary policy. On the other hand, stable inflation induces a binding financial constraint, which calls for monetary easing. Fortunately, the government is equipped with the credit policy to ease the financial strain and the tax policy to mitigate inflation. The trade-off is found to be resolved in favor of monetary easing, regardless of the availability of the tax policy. In summary, monetary policy should be eased in response to large, both positive and negative, productivity shocks around the stochastic steady state. However, while monetary easing in the state of high productivity is consistent with conventional wisdom, it depends crucially on the central bank's past commitments. When the central bank is less constrained by its past

[4] To be clear, this does not exclude the government budget constraint from playing an important role when, e.g., the economy is hit by a government spending shock.

commitments, the nominal interest rate tends to rise in response to unexpected productivity improvements.

Can the optimal policy be implemented by a familiar set of simple rules? I focus on the rules that let monetary policy respond to inflation and output, let credit policy respond to the credit spread, and let the labor tax rate be fixed. A more comprehensive study of optimal rules is left to future research. The optimized monetary rule echoes several findings in the literature, including a strong response to inflation but a muted response to output. Moreover, the inertia parameter exceeds but is close to 1, thus suggesting that the optimal monetary policy is forward looking and close to price-level targeting. The optimized credit rule is found to be modestly persistent, suggesting a slow unwinding of the central bank's balance sheet. The associated welfare losses are small, but the trade-off between inflation stability and financial stability is prominent. Relative to the Ramsey policy, the optimized rules feature too-aggressive credit interventions but insufficient monetary easing.

2. Related Literature

One of the main novelties of this paper is to jointly study two occasionally binding constraints (OBCs)—the financial constraint and the ZLB. The emphasis on the former is in line with Del Negro, Hasegawa, and Schorfheide (2016), Swarbrick, Holden, and Levine (2017), and Jensen et al. (2020), who have shown that such nonlinearity helps capture the sudden and discrete nature of financial crises and eliminate the financial acceleration mechanism in normal times. While these papers treat the financial constraint in a perfect-foresight manner, uncertainties surrounding the states of the constraint (binding or not) can have important implications. For example, Bocola (2016) finds that a liquidity facility like the European Central Bank's LTRO is ineffective when banks deem that the likelihood of hitting the financial constraint is high. In this paper, this kind of behavior is internalized by the Ramsey planner.

There is a large literature on monetary policy subject to the ZLB. A key lesson from this literature is that the nominal interest rate should be kept at the ZLB for a longer period of time than what a Taylor rule typically suggests (Eggertsson and Woodford 2003). Even when the nominal interest rate is positive, the presence of the ZLB calls for a more dovish monetary policy (Adam and Billi 2006; Nakov 2008) because the possibility of hitting the ZLB in the future reduces the output and inflation expectations today. In the early literature, the duration of the ZLB episode is largely exogenous, depending on a shock to the natural interest rate. Drawing on experience during the GFC, more recent work (Del Negro et al. 2017; Benigno, Eggertsson, and Romei 2020) models the origin of the ZLB episode as financial shocks that disrupt financial intermediation. This paper makes two contributions in this regard. First, I show that both positive and negative productivity shocks can drive the economy to the ZLB. Second, in contrast to the literature, the ZLB risk induces a relatively high nominal interest rate in normal times.

This paper also belongs to the growing literature on normative unconventional (credit) policy. Particularly, I share Bianchi (2016)'s emphasis on the risk-taking channel of unconventional policy. The idea is that (financial) firms need to balance the desire to invest today with the risk of becoming financially constrained in the future. They have an incentive to borrow more, knowing that the more they borrow, the larger the transfers they can receive from bailouts. The bailout policy faces the trade-off between the ex ante overborrowing and the ex post benefit of a faster recovery from a credit crunch. While this literature primarily focuses on time-inconsistent policy, Harrison (2017) studies optimal QE under discretion. He assumes a portfolio adjustment cost such that aggregate demand depends on both the short- and long-term interest rates. Hence, unlike in my model, QE works through a portfolio rebalancing channel and is effective only when the ZLB is binding.

A number of papers study optimized simple rules for unconventional policy. Foerster (2015) proposes a credit-spread-targeting rule with inertia. Conditional on monetary policy following a traditional Taylor rule, he concludes that a slow unwinding of the central bank's balance sheet is welfare improving. This is also found to be true in this paper provided that the credit policy is not too persistent. More generally, the optimal unconventional policy depends on the assumed monetary policy. Carrillo et al. (2017) study the interaction between conventional and unconventional monetary policy in a Bernanke–Gertler financial accelerator model. They focus on the relevance of Tinbergen's rule by comparing a monetary policy rule responding to both inflation and credit spreads with a dual-rule regime comprising a Taylor rule and a credit-spread-targeting financial rule. They find that the former responds too much to inflation and not enough to spreads, i.e., tight money and tight credit. In my model, the optimized monetary and credit rules are found to be too tight on money but too loose on credit.

Finally, this paper takes seriously the government budget constraint by excluding the government from access to lump-sum taxation. In most papers studying unconventional policy, it is assumed either explicitly or implicitly that the government budget constraint is not binding. The exceptions include Bianchi (2016), in which the government finances its bailout policy using a payroll tax and potentially a debt tax. However, Bianchi (2016) does not allow the government to borrow, because this would allow it to "lend" its borrowing capacity to financially constrained firms. Jiao (2019) considers an emerging economy relying on inflation and currency depreciation to finance unconventional policy. The focus of this paper is on advanced economies where the government finances its asset purchases by the optimal combination of distortionary taxes, seigniorage, and inflation. In this regard, this paper extends the optimal fiscal and monetary policy literature (e.g., Christiano, Chari, and Kehoe 1991; Schmitt-Grohé and Uribe 2004b; Siu 2004, among many others) by including a credit dimension. In this literature, the policy trade-off is between tax smoothing and price stability, which is resolved in favor of price stability even with small degrees of price rigidity. I find this result robust to the presence of financial frictions.

The rest of the paper is organized as follows. In the next section I present the model and the optimal policy problems. The quantitative method is described in section 4, followed by the main results in section 5. I examine the optimal simple rules in section 6. The last section concludes the paper.

3. Model

The model is based on a small version of Gertler and Karadi (2011), in which I abstract from a number of standard features that only matter quantitatively, e.g., working capital, variable capital utilization, and price indexation. The economy is populated by households, intermediate good producers, capital producers, financial intermediaries (referred to as banks), and a government. Intermediate good producers acquire labor and capital to produce differentiated goods, and set prices optimally when receiving a Calvo (1983) signal. Fixed investment is financed by state-contingent securities. Banks collect deposits from households subject to an agency problem and invest in the state-contingent securities, but their role in other important markets, e.g., mortgage, is abstracted. The government controls the nominal interest rate, purchases private securities, sets tax rates, and issues government bonds. The government may be able to vary lump-sum taxes, which can be used to remove the government budget from the Ramsey planner's constraints.

I depart from Gertler and Karadi (2011) in two important ways. First, I assume that the central bank sets the risk-free nominal interest rate, instead of the real rate. An important implication of this (more realistic) assumption is that monetary policy generating unanticipated inflation can affect the real borrowing cost of banks and the government. In this way, monetary policy interacts with credit and fiscal policy. Second, my model is a monetary economy with money demand and supply. Money demand encourages the central bank to stabilize the nominal interest rate rather than inflation, and money supply generates seigniorage incomes for the government.

3.1 Households

There is a unit-continuum of infinitely lived households. Households consume final goods c_t and supply labor l_t. They save in bank deposits D_t and fiat money M_t. Deposits are risk-free one-period nominal bonds carrying a gross rate of return R_t. Money facilitates consumption purchases. Households also own financial and non-financial firms.

Each household consists of workers and bankers who pool consumption risk perfectly. Workers are hired by intermediate good producers and bring wages to the household. Bankers manage a bank and transfer profits to the household. It is convenient to assume that households do not save in their own banks. The complete consumption insurance allows me to work with a consolidated representative household. The household chooses consumption, labor supply, and savings to maximize its life-time utility

$$\mathbb{W}_t = \left[\frac{(c_t - hc_{t-1})^{1-\sigma}}{1-\sigma} - \chi\frac{l_t^{1+\varphi}}{1+\varphi}\right] + \mathbb{E}_t\beta\mathbb{W}_{t+1}, \tag{1}$$

where $\sigma > 0$ is the measure of relative risk aversion, h is the habit parameter, $\chi > 0$ is the disutility weight on labor, $\varphi > 0$ is the (inverse of) Frisch elasticity of labor supply, and $0 < \beta < 1$ is the subjective discount factor. The household faces a budget constraint:

$$c_t[1 + s(v_t)] + \frac{M_t}{P_t} + \frac{D_t}{P_t} + \tau_t \leq w_t l_t(1 - \tau_{w,t}) + D_{t-1}\frac{R_{t-1}}{P_t} + \frac{M_{t-1}}{P_t} + \mathcal{F}_t,$$

where $s(v_t)$ is a proportional transaction cost of consumption purchases, P_t is the price of final goods, w_t is the real wage rate, $\tau_{w,t}$ is the labor tax rate, τ_t is lump-sum taxes, and $\mathcal{F}_t$ are the net real transfers from firms. The transaction cost takes the same function form as in Schmitt-Grohé and Uribe (2004b):

$$s(v_t) = \mathcal{A}v_t + \frac{\mathcal{B}}{v_t} - 2\sqrt{\mathcal{AB}},$$

where $v_t = \frac{P_t c_t}{M_t}$ is consumption-based money velocity, and $\mathcal{A}$ and $\mathcal{B}$ are parameters.

The first-order necessary conditions are

$$(c_t - hc_{t-1})^{-\sigma} - \mathbb{E}_t\beta h(c_{t+1} - hc_t)^{-\sigma} = \lambda_t^h(1 + 2\mathcal{A}v_t - 2\sqrt{\mathcal{AB}}),$$

$$\chi l_t^{\varphi}/\lambda_t^h = w_t(1 - \tau_{w,t}), \tag{2}$$

$$\mathbb{E}_t[\Xi_{t,t+1}r_{t+1}] = 1, \tag{3}$$

$$v_t^2 = \frac{\mathcal{B}}{\mathcal{A}} + \frac{R_t - 1}{\mathcal{A}R_t}, \tag{4}$$

where $\Xi_{t,t+1} \equiv \beta\frac{\lambda_{t+1}^h}{\lambda_t^h}$ is the stochastic discount factor and $r_{t+1} = \frac{R_t P_t}{P_{t+1}}$ is the real interest rate.

3.2 Non-financial Firms

There are two types of non-financial firms: capital producers and intermediate good producers.

3.2.1 Intermediate Good Producers

There is a continuum of intermediate good firms indexed by $m \in [0,1]$. They have access to a Cobb-Douglas technology $y_{m,t} = A_t(\xi_t k_{m,t-1})^{\alpha} l_{m,t}^{1-\alpha}$, where $0 < \alpha < 1$ is the capital share, A_t is total factor productivity, and $k_{m,t}$ is the capital stock at the end of period t. Let δ be the depreciation rate and ξ_t the quality of capital. Firm m acquires additional capital $i_{m,t} = k_{m,t} - (1-\delta)\xi_t k_{m,t-1}$. To finance its fixed investment, the firm issues securities $s_{m,t}$. Each unit of securities is a state-contingent claim to the future returns of one unit of capital. Following Gertler and Karadi (2011), capital and the securities have the same real price q_t under the assumption that $s_{m,t} = k_{m,t}$.[5] The real rate of return of holding securities for one period is given by

$$r_{k,t+1} \equiv \frac{z_{t+1} + (1-\delta)\xi_{t+1} q_{t+1}}{q_t}, \tag{5}$$

where z_t is the dividend rate on capital.

Let μ_t denote the real marginal cost. Cost minimization gives

$$w_t = (1-\alpha) A_t \left(\frac{\xi_t k_{m,t-1}}{l_{m,t}} \right)^{\alpha} \mu_t, \tag{6}$$

$$z_t = \alpha A_t (\xi_t)^{\alpha} \left(\frac{k_{m,t-1}}{l_{m,t}} \right)^{\alpha-1} \mu_t. \tag{7}$$

Firm m faces a downward-sloping demand function $y_{m,t} = \left(\frac{P_{m,t}}{P_t}\right)^{-\varepsilon_t} y_t$ derived from a final good aggregator $y_t = \left[\int_0^1 y_{m,t}^{\frac{\varepsilon_{t-1}}{\varepsilon_t}} dm\right]^{\frac{\varepsilon_t}{\varepsilon_{t-1}}}$, where $P_{m,t}$ is the price of intermediate good m and $\varepsilon_t > 0$ is the elasticity of substitution. With probability $1-\gamma$, firm m can optimize price $P^*_{m,t}$ subject to the demand function by solving

[5]This assumption implies that firms cannot borrow directly from households by paying a negative dividend. Otherwise the banking sector becomes trivial. Similar assumptions have been made in, e.g., Bianchi (2016), where the dividend payment is constrained from below.

$$\max \mathbb{E}_t \sum_{j=0}^{\infty} \gamma^j \Xi_{t,t+j} \left[\frac{P^*_{m,t}}{P_{t+j}} - (1+\tau_{y,t+j})\mu_{t+j} \right] y_{m,t+j},$$

where $\tau_{y,t}$ is a production tax. Focusing on a symmetric equilibrium, the first-order condition (FOC) is given by

$$\mathbb{E}_t \sum_{j=0}^{\infty} \gamma^j \Xi_{t,t+j} \left[(1-\varepsilon_t) \left(\frac{1}{\Pi_{s=1}^{j} \Pi_{t+s}} \right)^{1-\varepsilon_t} p^*_t + \varepsilon_t \left(\frac{1}{\Pi_{s=1}^{j} \Pi_{t+s}} \right)^{-\varepsilon_t} (1+\tau_{y,t+j})\mu_{t+j} \right] y_{t+j} = 0, \quad (8)$$

where $\Pi_t = \frac{P_t}{P_{t-1}}$ is inflation and $p^*_t = p^*_{m,t} = \frac{P^*_{m,t}}{P_t}$ is the optimized real price of intermediate goods.

3.2.2 Capital Producers

Capital producers face a cost function $f(\cdot) = i_t + \frac{\eta}{2}\left(\frac{i_t}{\delta k_{t-1}} - 1\right)^2 \delta k_{t-1}$ with $\eta \geq 0$[6] and price new capital optimally according to

$$q_t = 1 + \eta \left(\frac{i_t}{\delta k_{t-1}} - 1 \right). \quad (9)$$

3.3 Banks

Banks are financial intermediaries engaging in maturity and liquidity transformation. A bank receiving deposits amounting to D_t from households and purchasing s_t units of securities from intermediate good producers has the balance sheet

$$q_t s_t = \frac{D_t}{P_t} + n_t,$$

[6] Another popular specification of the cost function is $f(\cdot) = i_t + \frac{\eta}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 i_t$, which renders a more complicated FOC. However, the results under both specifications are quantitatively similar.

where n_t is the bank's real net worth at the beginning of period t.[7] The net worth evolves according to

$$\begin{aligned} n_t &= q_{t-1}s_{t-1}r_{k,t} - D_{t-1}\frac{R_{t-1}}{P_t} \\ &= q_{t-1}s_{t-1}(r_{k,t} - r_t) + n_{t-1}r_t, \end{aligned}$$

where in the second line I use the balance sheet equation to substitute for $\frac{D_t}{P_t}$. The bank's leverage is defined as

$$\phi_t = \frac{q_t s_t}{n_t}.$$

As in Gertler and Karadi (2011), each bank shuts down with probability r_n at the end of each period, upon which the bank distributes its net worth to its household.[8] Then, bankers become workers. In the meantime, a similar number of workers from the same household randomly become new bankers. New bankers receive "start-up" funds from their household as a proportion ϖ of the total value of capital in the economy.[9]

Each bank chooses an investment plan s_t to maximize its expected present value of net worth upon closure:

$$\begin{aligned} V_t(n_t) &= \max \mathbb{E}_t \sum_{j=0}^{\infty} r_n(1-r_n)^j \Xi_{t,t+j+1} n_{t+1+j} \\ &= \max \mathbb{E}_t \Xi_{t,t+1}[r_n n_{t+1} + (1-r_n)V_{t+1}(n_{t+1})] \\ &= \nu_{n,t} n_t, \end{aligned}$$

where the third equality follows a conjecture that the value function is linear in net worth with an unknown time-varying coefficient $\nu_{n,t}$. The bank faces an agency problem that implies an upper bound

[7] It is easy to show that each bank is a scaled version of the others. The heterogeneity in their net worth and asset holdings does not affect their aggregate behaviors. See Gertler and Karadi (2011).

[8] The notation r_n follows the idea that the probability of shutting down can be interpreted as an exogenous dividend rate.

[9] In Gertler and Karadi (2011), the start-up funds are proportional to the assets held by incumbent banks. I make this minor change to ensure that start-up funds are not affected by the central bank's asset purchasing.

on its leverage level (i.e., the financial constraint; see Gertler and Karadi 2011 for details):

$$\frac{\nu_{n,t}}{\theta_t} - \phi_t \geq 0, \tag{10}$$

where $\theta_t \in [0,1]$ is an exogenous process controlling the tightness of the constraint, and shocks to θ_t are referred to as financial shocks capturing "Minsky moments" in a reduced form (e.g., disturbances to haircuts that change the effective value of net worth).

Let the multiplier associated with (10) be $\lambda_t \geq 0$. The necessary conditions of the bank's problem include the complementary slackness condition

$$\left(\frac{v_{n,t}}{\theta_t} - \phi_t\right)\lambda_t = 0, \tag{11}$$

and the first-order condition

$$\begin{aligned} \mathbb{E}_t \Xi_{t,t+1}(r_n + (1 - r_n)\nu_{n,t+1})(r_{k,t+1} - r_{t+1}) &\equiv \nu_{s,t} \\ &= \frac{\lambda_t}{1+\lambda_t}\theta_t \geq 0. \end{aligned} \tag{12}$$

The unknown coefficient $\nu_{n,t}$ can be solved using (10) and (12):

$$\nu_{n,t} = \nu_t\left(\frac{\nu_{s,t}}{\theta_t - \nu_{s,t}} + 1\right), \tag{13}$$

where $\nu_t \equiv \mathbb{E}_t \Xi_{t,t+1}(r_n + (1 - r_n)\nu_{n,t+1})r_t$. Note that $\nu_{s,t}$ is forward looking when the financial constraint is binding and equal to zero (i.e., independent of future states) otherwise. It follows that successful policy can narrow the credit spread today by reducing the probability of hitting the financial constraint in the future.

3.4 The Government

Following the standard approach in the public finance literature, the specific agency that implements each policy is abstracted from the model. By focusing on a consolidated government, it is implicitly assumed that the central bank can receive fiscal support for its balance sheet, which could be particularly necessary when the balance sheet is large (Del Negro and Sims 2015; Benigno and Nisticò 2020). The government holds a proportion $\mathcal{P}_t \in [0, 1]$ of the total securities issued by intermediate good producers,[10] which renders a quadratic resource cost

$$\tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2,$$

where $\tau_{\mathcal{P}} \geq 0$ is a parameter. Following the literature (Gertler and Karadi 2011; Dedola, Karadi, and Lombardo 2013; Foerster 2015), this cost represents inefficient public activities in private financial markets or the cost of strengthened financial surveillance.[11] Because of this cost, the government's asset purchases may increase the fiscal burden even when the credit spread is positive.

The consolidated budget constraint is given by

$$g_t + \frac{R_{t-1}}{\Pi_t} b_{t-1} + \frac{m_{t-1}}{\Pi_t} + \mathcal{P}_t q_t s_t + \tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2 =$$
$$\tau_t + w_t l_t \tau_{w,t} + \int_0^1 \tau_{y,t} \mu_t y_{m,t} dm + b_t + m_t + \mathcal{P}_{t-1} q_{t-1} s_{t-1} r_{k,t}, \tag{14}$$

where tax revenues include labor taxes $w_t l_t \tau_{w,t}$, production taxes $\int_0^1 \tau_{y,t} \mu_t y_{m.t} dm$, and lump-sum taxes τ_t; g_t is exogenous wasteful government consumption; $m_t = \frac{M_t}{P_t}$ are real money balances; $b_t = \frac{B_t}{P_t}$; and B_t is a one-period state-noncontingent nominal asset. As in Gertler and Karadi (2011), B_t can be interpreted as either government bonds or reserves. In the former case, D_t denotes the sum of bank deposits and government bonds held by households. In the latter case, B_t is part of the bank assets. Assuming that the agency problem does not apply to reserves, B_t simply drops out of the bank's problem.

[10] In an early version of this paper, I compare the three credit measures laid out by Gertler and Kiyotaki (2010), namely asset purchases, liquidity facilities, and liquity injections. It can be shown that without any further distortions introduced in the model, these measures only differ in a trivial way. I focus on an asset purchase program in this paper because it is the easiest to understand.

[11] Dedola, Karadi, and Lombardo (2013) add a linear term in the cost function, but they only find the coeffcient on the quadratic term playing an important role.

3.5 Competitive Equilibrium

DEFINITION 1. *Given policies* $\{\tau_{w,t}, \tau_{y,t}, R_t, \mathcal{P}_t, \tau_t\}$*, exogenous processes* $\{A_t, \xi_t, \theta_t, g_t, \varepsilon_t\}$*, and initial conditions, a competitive equilibrium of aggregate dynamics is a set of plans*

$$\{c_t, l_t, m_t, P_t^*, \Pi_t, \iota_t, y_t, \mu_t, k_t, s_t, w_t, z_t, q_t, i_t, \nu_{n,t}, n_t, b_t\},$$

satisfying the FOCs of the household (2, 3, 4), the FOCs of non-financial firms (6, 7, 8, 9), the Karush–Kuhn–Tucker conditions and value function of the bank ($\lambda_t \geq 0$*, 10, 11, 12, 13), the aggregate production function*

$$y_t \iota_t = A_t(\xi_t k_{t-1})^{\alpha} l_t^{1-\alpha}, \tag{15}$$

the following laws of motion (for, respectively, the price index, price dispersion, capital, and the aggregate net worth):

$$1 = (1-\gamma)p_t^{*1-\varepsilon_t} + \gamma \Pi_t^{\varepsilon_t - 1}, \tag{16}$$

$$\iota_t = (1-\gamma)p_t^{*-\varepsilon_t} + \gamma \Pi_t^{\varepsilon} \iota_{t-1}, \tag{17}$$

$$k_t = i_t + (1-\delta)\xi_t k_{t-1}, \tag{18}$$

$$n_t = (1-r_n)(q_{t-1}s_{t-1}\mathcal{P}_{t-1}(r_{k,t} - r_t) + n_{t-1}r_t) + \varpi q_{t-1}s_{t-1}, \tag{19}$$

the government budget constraint (14), and finally two market clearing conditions

$$y_t = c_t[1 + s(\upsilon_t)] + f(k_{t-1}, i_t) + \tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2 + g_t, \tag{20}$$

$$s_t = k_t, \tag{21}$$

where λ_t^h*,* υ_t*,* $r_{k,t}$*,* $\nu_{s,t}$*, and* ν_t *are defined in the text, and* $\iota_t \equiv \int_0^1 \left(\frac{P_{m,t}}{P_t}\right)^{-\varepsilon_t} d_m$.

3.6 Policy

The jointly optimal credit, monetary, and fiscal policy is a set of plans $\{\tau_{w,t}, \tau_{y,t}, R_t, \mathcal{P}_t, \tau_t\}$ that maximizes (1) subject to the competitive equilibrium.[12] There are three sources of inefficiency in the

[12]The problem can be somewhat simplified by noting that (12) is a redundant constraint at least locally around the chosen steady state. This can be

model, namely the financial constraint, nominal rigidity, and imperfect competition.[13] I focus on the first two sources and assume throughout the paper that the inefficiency of imperfect competition is offset by a constant production subsidy $\tau_y = -\frac{1}{\bar{\varepsilon}}$.[14]

Formally, I consider the following Ramsey problem.

DEFINITION 2. *A debt Ramsey equilibrium solves* $\{\tau_{w,t}, R_t, \mathcal{P}_t\}$ *to maximize (1) subject to the competitive equilibrium and the ZLB,* $\ln R_t \geq 0$. *There is a production subsidy* $\tau_y = -\frac{1}{\bar{\varepsilon}}$ *financed by fixed lump-sum taxes. The net government deficit is financed by public debts.*

Since the first-order condition with respect to public debt features a unit root, the local approximation technique used to solve the model (to be discussed later) is inaccurate in long simulations, which are necessary to compute most interesting statistics in my highly nonlinear model. Moreover, the accuracy can be particularly poor when I calculate welfare using a second-order approximation. Therefore, it is convenient to consider a stationary "lump-sum Ramsey equilibrium," in which the government budget is not a binding constraint.

DEFINITION 3. *A lump-sum Ramsey equilibrium solves* $\{\tau_{w,t}, R_t, \mathcal{P}_t\}$ *to maximize (1) subject to the competitive equilibrium and the ZLB,* $\ln R_t \geq 0$. *There is a production subsidy* $\tau_y = -\frac{1}{\bar{\varepsilon}}$. *Lump-sum taxes are set to balance the government budget period by period. The steady-state labor tax rate is not chosen optimally but set equal to that of the debt Ramsey equilibrium, which equates the steady states of both equilibria. Effectively, the lump-sum Ramsey planner chooses deviations of the labor tax rate from its steady states.*

---

confirmed in a quantitative analysis, as the Lagrange multiplier associated with this constraint always equals zero. Intuitively, the government has no incentive to overinvest in physical capital.

[13] One may consider money demand motivated by a transaction cost and the costly capital production as extra sources of distortion.

[14] This assumption is unlikely to change my main results. As shown by Schmitt-Grohé and Uribe (2004a), imperfect competition only shifts average optimal inflation upwards. This is because the social planner would like to tax money balances as an indirect way to tax monopoly profits.

In the lump-sum Ramsey equilibrium, the main difference between the chosen steady state and its optimal steady state concerns the labor tax rate, which is 30 percent in the former and −0.05 percent in the latter under my calibration. I focus on the high-tax steady state for three reasons: (i) the average tax wedge across OECD countries is about 37 percent between 2000 and 2019 according to OECD Tax Statistics; (ii) to make the debt and lump-sum Ramsey equilibria more comparable; and (iii) to capture labor market imperfections that are not explicitly modeled. In Appendix A, I show that the lump-sum Ramsey equilibrium behaves similarly to the debt Ramsey equilibrium provided that they share the same steady state. Therefore, the lump-sum Ramsey model is employed as the workhorse model throughout the paper and is referred to simply as the Ramsey equilibrium/model for convenience. In solving the Ramsey equilibrium, I follow the "timeless" perspective advocated by Woodford (2003). First-order conditions are derived using MATLAB's symbolic toolbox. Then, the equilibrium is represented by a system of difference equations, which can be solved numerically using the method discussed in the next section. I compare the Ramsey equilibrium to a laissez-faire equilibrium defined as follows:

Definition 4. *A laissez-faire equilibrium is a competitive equilibrium where* $\mathcal{P}_t = 0, \tau_{w,t} = \bar{\tau}_w$, *and the monetary policy follows a conventional Taylor rule*

$$\log \frac{R_t}{\bar{R}} = \max \left\{ 0.8 \log \frac{R_{t-1}}{\bar{R}} + (1-0.8) \left(1.5 \log \frac{\Pi_t}{\bar{\Pi}} + 0.125 \log \frac{y_t}{\bar{y}} \right), - \log \bar{R} \right\},$$

where $\bar{R}_t$, $\bar{\tau}_w$, $\bar{\Pi}$, *and* $\bar{y}$ *are the steady-state variables. Once more, lump-sum taxes are set to balance the government budget period by period. The steady-state labor tax rate and inflation are set equal to those of the debt Ramsey equilibrium so that both equilibria have the same steady state.*

Now I briefly discuss policy trade-offs and then move to quantitative exercises.

3.7 Policy Trade-Offs

By purchasing private securities, the government acts as a financial intermediary. Since the government faces no financial constraint, credit policy effectively replaces inefficient financial intermediaries (banks) with an efficient one (the government). The policy pass-through is as follows. When the financial constraint is binding, banks are forced to deleverage by selling their assets. This creates a decline in aggregate demand, lowering both output and inflation. Credit policy makes up for the shortfall in asset demand, which improves asset prices and hence the bank net worth through a capital gain. Consequently, the financial constraint is relaxed and the credit spread narrows. However, the government may not absorb all assets sold off because of the recourse cost. At the margin, there could be a small yet positive credit spread. In this case, banks are crowded out from profitable investment and need more time to rebuild their net worth.

When the output gap and inflation move in the same direction, monetary policy ought to be a powerful tool. However, as noted in Carrillo et al. (2017), monetary policy may not be able to simultaneously stabilize both the output gap and inflation in the presence of a financial accelerator mechanism. In addition to the standard Euler equation channel, monetary policy also affects the financial constraint through its ability to adjust the real interest rate; see (19) and (10).[15] To minimize the credit spread, the central bank may tolerate positive inflation at the margin. This trade-off between

[15]How monetary policy affects the financial constraint is a key determinant of its effectiveness. In Brunnermeier and Koby (2017), monetary easing relaxes the constraint until reaching a reversal rate, below which further easing tightens the constraint and reduces lending. In Cavallino and Sandri (2019), monetary easing tightens the constraint when the economy faces a premium on international financial markets. In this paper, I focus on the ZLB as a liquidity trap rather than the reversal bound of Brunnermeier and Koby (2017). Indeed, the reversal rate seems to be somewhere below the ZLB (or some small negative number if the lower bound is not zero). See, for example, a speech by Benoît Cœuréthe in 2016: https://www.ecb.europa.eu/press/key/date/2016/html/sp160728.en.html. Above the reversal rate, empirical work (e.g., Alessandri and Nelson 2015) finds that monetary easing can strengthen the balance sheet condition of financial intermediation. In Brunnermeier and Sannikov (2016), this positive effect originates from capital gains. In my model and Carrillo et al. (2017), this positive effect is also captured by the ability of monetary policy to control the short-term real interest rate.

financial stability and inflation stability can be particularly significant if an inflationary shock tightens the financial constraint, e.g., a negative TFP shock. In these cases, it is helpful to have the labor tax policy that gives the government an extra margin to affect inflation. The distortionary labor tax can also be used to affect asset prices through the capital-labor ratio, i.e., an increase in labor supply must be matched by an increase in investment demand. Since movements in asset prices are key to the financial accelerator mechanism, this tax policy can be used to ease the financial strain.

If the government commits to addressing financial frictions, banks expect higher asset prices and lower borrowing costs under financial distress. Knowing that future financial crises will have a smaller impact on them, banks are willing to take on higher leverage in normal times, resulting in more fixed investment. This is the risk-taking channel that is relevant to all three policies. However, the more deeply banks are leveraged, the more likely they are to hit the financial bound. Consequently, the government has to conduct costly interventions more often. In this way, the government faces a trade-off in encouraging risk-taking behavior (or discouraging precautionary behavior). As noted by Bianchi (2016), the risk-taking channel makes optimal policy time-inconsistent. The government is tempted to announce a relatively small stimulation package ex ante, which is not optimal ex post.

4. Quantitative Method

Ideally the model should be solved by global methods. However, the Ramsey equilibrium contains too many state variables, some of which are multipliers associated with forward-looking constraints.[16] The model is therefore difficult to solve even using methods that are explicitly designed to deal with large state space, such as that of Maliar and Maliar (2015). Fast algorithms such as that of Guerrieri

[16]Bianchi (2016) solves the Ramsey policy in a model with occasionally binding financial constraints by policy function iteration. When there are not enough instruments to render constrained-efficient allocations, the system contains seven state variables in total, two of which are multipliers associated with forward-looking constraints.

and Iacoviello (2015) based on piecewise linearization give, however, certainty equivalent results.

I employ the approach of Holden (2016), which can easily be implemented by Holden's DynareOBC toolkit.[17] The core algorithm is based on Holden (2019), which solves models that are linear apart from OBCs under perfect foresight. The idea of this algorithm is to hit the inequality-constrained variables with endogenous news (anticipated) shocks such that the inequality constraint is always satisfied. Solving the model amounts to finding the appropriate news shocks, which can be represented by a linear complementarity problem. The solution is virtually the same as the one computed by Guerrieri and Iacoviello (2015)'s algorithm. The main advantage of Holden (2016)'s generalized algorithm is to allow me to capture the role of risk. First, it can solve models that are nonlinear apart from OBCs by high-order approximations. Second, the risk of hitting OBCs can be taken into account in the spirit of Adjemian and Juillard (2013), i.e., by integrating the model over a certain period of future uncertainties to approximate rational expectations. To balance between accuracy and speed, I use 50 periods in practice.

Throughout the paper, I compute second-order approximations of the model under rational expectations (RE, with integration over future uncertainties). Hence, I capture the precautionary effects stemming from both OBCs and second-order terms. To see how OBC-related risks affect model behavior, I also compute a "perfect-foresight" (PF) solution by assuming that economic agents ignore the possibility of hitting OBCs in the future and are always surprised when hitting OBCs.[18]

4.1 Calibration

The calibration goal is not to match statistical moments of a wide range of macroeconomic variables, but rather to generate enough uncertainty such that the precautionary effects are quantitatively reasonable. Most parameters take their conventional values in the

[17]DynareOBC is available at https://github.com/tholden/dynareOBC.

[18]I abuse the term "PF" slightly because the "PF" solution still captures precautionary effects stemming from second-order terms. In practice, the "PF" solution is computed without integrating future uncertainties.

Table 1. Fixed and Calibrated Parameters

Description	Parameter	Value
Fixed Parameters		
Relative Risk Aversion	σ	2
Habit	h	0.7
Frisch Elasticity (Inverse)	φ	0.4
Parameter of Consumption Transaction Cost	$\mathcal{A}$	0.0111
Parameter of Consumption Transaction Cost	$\mathcal{B}$	0.07524
Calvo Parameter	γ	0.779
Markup (Steady State)	$\frac{\bar{\varepsilon}}{\bar{\varepsilon}-1} - 1$	0.2
Capital Share	α	0.33
Depreciation Rate	δ	0.025
Elasticity of Investment (Inverse)	η	1.728
Survival Probability of Banks	$1 - r_n$	0.972
Transfer Rate from Households to New Banks	ϖ	$\frac{1-(1-r_n)/\beta}{4}$
Fraction of Divertible Assets (Steady State)	$\bar{\theta}$	0.247
Gov. Consumption-to-GDP Ratio (Steady State)	$\frac{\bar{g}}{\bar{y}}$	0.2
Credit Policy Cost	$\tau_{\mathcal{P}}$	0.0005
TFP Persistence	ρ_A	0.094
TFP St. D.	σ_A	0.0035
Calibrated Parameters		
Labor Disutility Weight	χ	48
Gov. Debt-to-GDP Ratio (Steady State)	$\frac{\bar{b}}{\bar{y}}$	0.7
Discount Factor	β	0.9987
Financial Shock Persistence	ρ_θ	0.8
Financial Shock St. D.	σ_θ	0.017

literature, which are summarized in the upper panel of table 1. The inverse Frisch elasticity φ is set to 0.4 and the relative risk aversion is set to 2, both within typical ranges in the literature. The Calvo parameter γ and the inverse elasticity of investment η are borrowed from Gertler and Karadi (2011). The parameters of the consumption transaction cost are borrowed from Schmitt-Grohé and Uribe (2004b). The parameter of the resource cost is set to 0.0005. As there is no hard evidence to quantify this cost, $\tau_{\mathcal{P}}$ is picked rather arbitrarily only to ensure that credit policy is not dominated by other policies. But my results are robust to reasonable variations in $\tau_{\mathcal{P}}$.

There are three parameters in the financial sector, namely r_n, $\bar{\theta}$, and ϖ. Following Gertler and Karadi (2011), I choose the survival rate $1 - \bar{r}_n$ that implies a decade of banks' average lifetime. I set the steady-state leverage ratio $\bar{\phi}$ to 4, which is considered as an average across sectors with vastly different financial structures.[19] Next, I choose a deterministic steady state where the financial constraint is slack and the credit spread is zero.[20] This choice is supported by Bocola (2016)'s estimate in a similar model where the Lagrange multiplier associated with the financial constraint is close to zero on average. My choices of η and r_n are also broadly consistent with Bocola (2016)'s estimates. The transfer rate to new banks is pinned down by the leverage ratio $\varpi = \frac{1-(1-r_n)/\beta}{\bar{\phi}}$. The steady-state proportion of divertable assets $\bar{\theta}$ is adjusted such that the financial constraint is close to its bound in the steady state ($\bar{\theta} = 0.247$). This is to ensure reasonable accuracy of approximation when the financial constraint is binding.

Calibrated parameters are shown in the lower panel of table 1. There are two parameters affecting the optimal labor taxes. I pick $\chi = 48$ to match the steady-state working hours of about 40 hours (i.e., 24 percent) per week. The government debt-to-GDP ratio is set to 0.7, in line with the relatively high levels of public debt in many advanced economies in recent years.[21] To quantify the ZLB risk, I use a relatively large discount factor to capture a low neutral interest rate. $\beta = 0.9987$ implies a steady-state real interest rate of 0.52 percent, matching the average yield on U.S. 10-year Treasury inflation-indexed securities between 2009 and 2019.

The behavior of nonlinear models crucially depends on the specification of shocks. To avoid making the model too difficult to solve,

---

[19] The literature has suggested alternative calibrations. For example, $\bar{r}_n$ can be set to match a dividend rate of 5.15 percent made by the 20 largest U.S. banks during 1965–2013 (Swarbrick, Holden, and Levine 2017). The steady-state leverage can be set to 16, the estimate of Quint and Rabanal (2017) in which the authors use GMM to estimate a similar model with the financial constraint always binding. These values change my results quantitatively but not qualitatively.

[20] It is well known that kinks of either the ZLB or borrowing constraints can introduce multiple equilibria. First, there are multiple deterministic steady states. I focus on a normal steady state with positive nominal interest rates and a silent credit policy. Second, there can be multiple paths reverting to a given steady state. Holden (2019)'s method allows one to test and select from these paths. Throughout the paper, should multiple paths emerge, I choose the one that escapes the bound as soon as possible.

[21] Note that B_t denotes government bonds held by the public, excluding those held by the central bank. The relevant ratio in the United States is between 0.7 and 0.8 in recent years.

I only consider two shocks: a TFP (supply) shock A_t and a financial (demand) shock θ_t. I assume both shocks following log-AR(1) processes. The specification of the TFP shock is fixed (not calibrated) to the post-1983 estimates of Smets and Wouters (2007) and fits the Solow residuals reasonably well (see, e.g., Jermann and Quadrini 2012), with an autocorrelation coefficient equal to 0.94 and the standard deviation of its innovations equal to 0.35 percent. Next, the persistence of θ_t is 0.8, following Romer and Romer (2017)'s finding that financial distress itself is fairly persistent. To pin down the standard deviation of the financial shock, I solve the laissez-faire equilibrium, ignoring the ZLB, and match the standard deviation of the annualized credit spread (0.7 percent).[22] However, without features such as true default risk, I inevitably underestimate the average credit spread (2.07 percent in data versus 0.18 percent in the model). Or I would overestimate the standard deviation if I matched the mean. Since the financial constraint is occasionally binding, the standard deviation appears to be the more natural choice for calibration.[23]

5. Quantitative Results

5.1 Simulations

Table 2 reports key statistics of the Ramsey and laissez-faire equilibrium. Rows (a) and (c) present the ergodic mean and standard deviations under rational expectations. Rows (b) and (d) present the same ergodic statistics under perfect foresight.

First consider the laissez-faire equilibrium. Rows (a) and (b) show that precautionary effects stemming from OBCs induce the financial constraint less often binding in the RE model (19.01 percent) than in the PF model (27.33 percent). Since the financial constraint imposes an upper bound on leverage, the average level of leverage is lower in the PF model. On average, the precautionary

[22] The data is Moody's seasoned Bbb corporate bond yield relative to the yield on 10-year treasury, 1983:Q1–2019:Q1. I ignore the ZLB here mainly because simulating the laissez-faire equilibrium with the ZLB is extremely slow.

[23] When the financial constraint is always binding, Gertler and Kiyotaki (2010) and Dedola, Karadi, and Lombardo (2013) target the average spread of 1 percent.

Table 2. Long-Run Properties of the Ramsey and Laissez-Faire Equilibrium

	Log y_t	*Log* Π_t	*Log* R_t	*ZLB*	*Spread*	ϕ_t	*FC*	$\mathcal{P}_t$
Laissez-faire								
(a) RE	−10.90	0.15	0.31	5.16	0.21	4.12	19.01	0.00
	(0.55)	(0.39)	(0.19)	—	(0.55)	(0.45)	—	(0.00)
(b) FF	−10.67	0.12	0.27	9.29	0.25	4.10	27.33	0.00
	(0.63)	(0.39)	(0.19)	—	(0.62)	(0.47)	—	(0.00)
Ramsey								
(c) RE	−9.70	0.02	0.12	11.81	0.00	4.00	51.29	0.95
	(0.51)	(0.02)	(0.11)	—	(0.00)	(0.08)	—	(0.99)
(d) PF	−9.81	0.00	0.07	31.41	0.00	3.89	15.58	0.12
	(0.53)	(0.01)	(0.08)	—	(0.00)	(0.11)	—	(0.39)

Note: Rows labeled RE (PF) are ergodic statistics under rational expectations (perfect foresight), calculated using simulated series of 10,000 periods. Numbers outside (inside) the parentheses are the mean (standard deviations). The column labeled ZLB (FC) is the frequency when the ZLB (financial constraint) is binding. The log transformed variables are multiplied by 100; ratios and rates are in percentage points; the leverage is in level.

effects reduce output by 0.23 percent but improve economic stability (reducing volatility) and financial efficiency (narrowing the credit spread). The RE economy also experiences fewer ZLB episodes. This is because deleveraging under financial distress leads to low inflation, which prompts the central bank to cut the nominal interest rate.

In the Ramsey equilibrium, rows (c) and (d) show that optimal policy raises the average output by 1.2 percent or 0.86 percent relative to the laissez-faire policy, depending on how expectations are calculated. Moreover, the average nominal interest rate is lower, suggesting a more dovish monetary policy in general. A key feature of the Ramsey equilibrium is that the optimal credit spread is virtually zero at all times. To further investigate this outcome, I solve the credit spread in Ramsey equilibria with different steady-state labor tax rates. I find that both the mean and standard deviation of the optimal credit spread approaches zero quickly as the steady-state labor tax increases (a plot of this result is left to Appendix B). Quantitatively, a country with a labor tax rate greater than 10 percent should fully stabilize its credit spread. The intuition is that financial distress becomes increasingly painful when the labor market is more distorted because the markets for production factors—labor and capital—are inefficient. Hence, the benefits of narrowing the credit spread dominate the associated cost. Given the expectation of a zero credit spread, banks have an incentive to take on higher leverage. Therefore, relative to the PF model, the RE model features higher output, leverage, and a more frequently binding financial constraint which, in turn, requires more asset purchases and tax rebates on average.

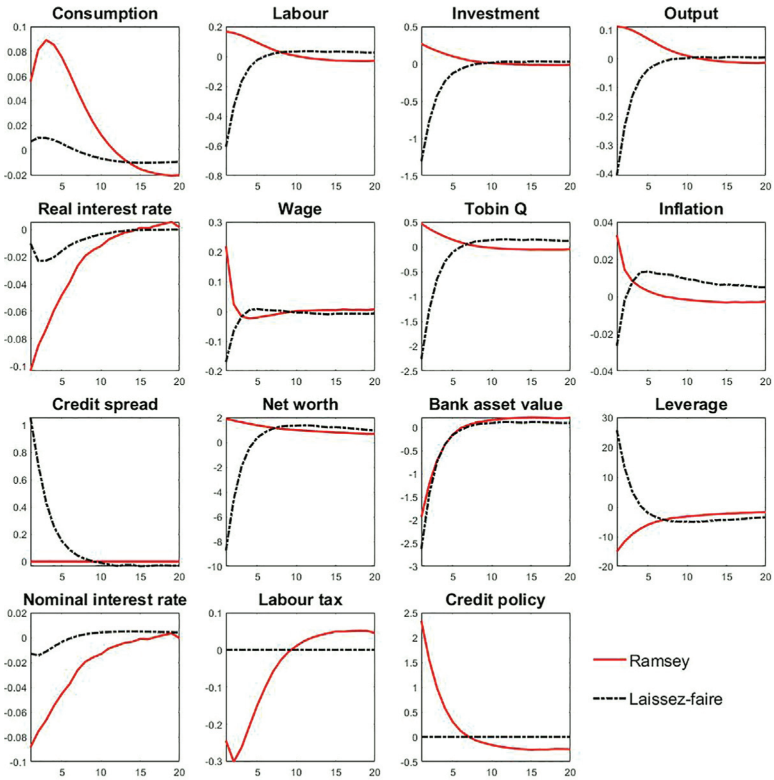
Surprisingly, the average nominal interest rate is higher in the RE model. One possible explanation is that the Ramsey model simply hits the ZLB less often. But the causality can also be reversed. I argue that the central bank intends to keep monetary policy relatively tight, which leads to fewer ZLB episodes. To illustrate this point, I consider the risky steady state (RSS) defined as in Coeurdacier, Rey, and Winant (2011), which is the fixed point of the economy when expectations take into account future risk.[24] I calculate four RSSs (left to Appendix B) based on the economy with none, one, or both of the OBCs, respectively. If there is only one OBC, either the financial constraint or the ZLB, I find the same result as in the literature (e.g., Adam and Billi 2006) that the central bank loosens its monetary policy relative to the no-OBC case. However, the presence of the ZLB and the financial constraint together constitute a much more significant risk. In this case, the RSS features a permanent credit intervention, a lower labor tax rate, but a higher nominal interest rate relative to the no-OBC case. The fact that this policy mix is found to be optimal must mean that the monetary policy is less effective when both OBCs bind simultaneously: the benefits of monetary easing at the ZLB (e.g., through a commitment to future interest rates) is limited by the partial transmission from r_t to $r_{k,t}$.

5.2 Impulse Response Analysis

To take a closer look at optimal policy, I consider impulse responses to a positive financial shock, a positive TFP shock, and a negative TFP shock, all of three standard deviations. Figures 1–3 show

[24] In practice, RSSs are obtained by simulating the economy under rational expectations with all realized shocks equal to zero until reaching a fixed point.

Figure 1. Impulse Response to a Positive Financial Shock



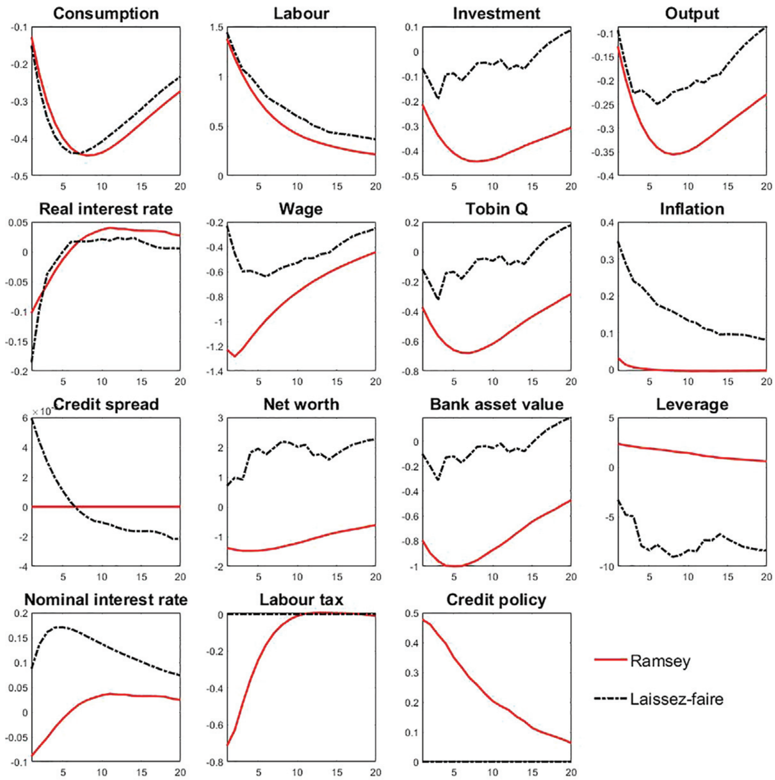
Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

the mean expected impulse response functions (generalized IRFs of Koop, Pesaran, and Potter 1996) to each shock as deviations from the stochastic steady state.[25] In each figure, rows from top to bottom show real activity, relative prices, financial variables, and policy instruments, respectively.

First consider responses to the financial shock shown in figure 1. Given the binding financial constraint, banks fire-sell their assets. In the laissez-faire equilibrium, this makes the asset prices sharply

[25]Generalized IRFs are calculated using 500 simulations with 500 periods of burn-in. Since the path of the OBCed variable is averaged across varying initial states, the kinks are largely smoothed out.

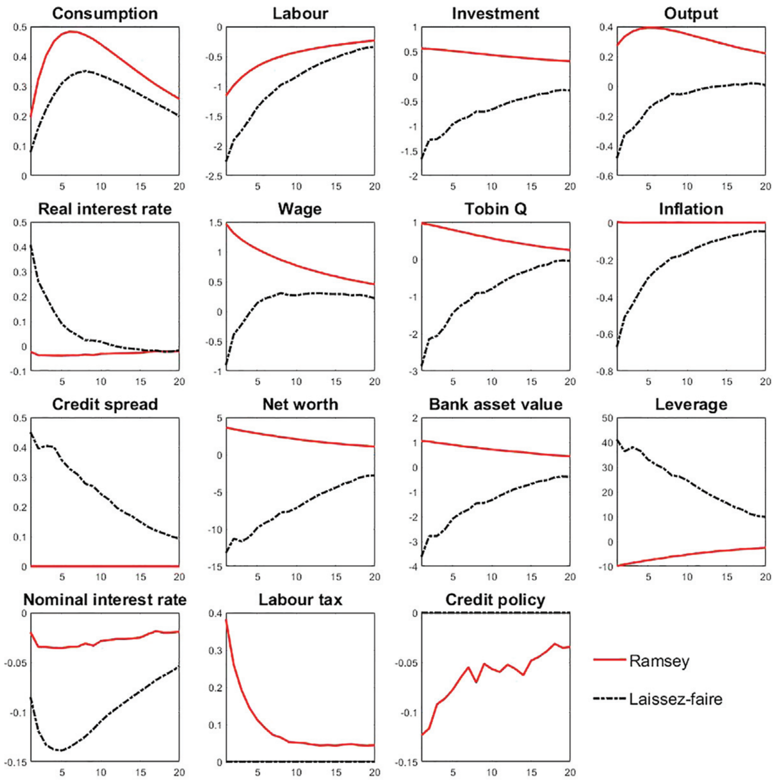
Figure 2. Impulse Response to a Negative TFP Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations. The response of the laissez-faire equilibrium is volatile because the reported path is the average of a large number of simulations, some of which involve a binding financial constraint and/or the ZLB.

lower, which feeds back into bank net worth and further tightens the financial constraint. The inefficiency in financial intermediation forces households to increase their consumption. The surge in credit spread is supportive towards the marginal cost, mitigating disinflationary pressure (inflation down by 0.02 percent). Since the standard Taylor rule responds primarily to inflation, the reaction of monetary policy is largely muted. By contrast, the optimal monetary policy focuses more on relaxing the financial constraint by tolerating a modest increase in inflation. Nonetheless, thanks to a labor tax rebate,

Figure 3. Impulse Response to a Positive TFP Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

the increase in inflation is manageable (a little more than 0.03 percent). Regarding credit policy, the asset purchase program is fairly aggressive (more so if the ZLB is binding) and unwinds as banks releverage. Unlike the laissez-faire equilibrium where banks deleverage slowly, the deleveraging process is instantly completed in the Ramsey equilibrium. This is thanks to the positive policy effects on bank net worth through a lower borrowing cost on bank liabilities and a capital gain on bank assets. Note that given a zero credit spread, the selling of assets to the central bank does not negatively affect banks' profitability.

Upon a negative TFP shock, the capital return should fall in the first-best equilibrium (under flexible prices and efficient financial markets) because $z_t = \alpha \frac{y_t}{k_{t-1}} \mu$ where the marginal cost is a constant. In the presence of nominal rigidity, the real interest rate is generally below its first-best level, meaning that the marginal cost and the capital return are above their first-best levels. However, these inefficient adjustments of the economy are beneficial to banks. Therefore, the laissez-faire equilibrium shown in figure 2 features improved net worth and a small credit spread. On the other hand, the Ramsey equilibrium tries to replicate the first-best allocation by raising the real interest rate. This is partially achieved by a labor tax rebate, which lowers wages and inflation. Naturally, both a higher real rate and a lower z_t tighten the financial constraint, making it necessary to employ credit policy. At a first glance, figure 2 seems to suggest that the highly expansionary Ramsey policy only worsens the economic performance. But the discussion above should make it clear that the Ramsey allocation is in fact closer to the first-best allocation.

At last, consider a positive TFP shock. In the laissez-faire equilibrium, higher productivity should relax the financial constraint thanks to the improved return on bank assets. However, when the shock is large enough to render a binding ZLB, the resulting demand shortfall widens suddenly. Consequently, asset prices fall and the financial constraint binds, dragging the economy into the spiral of Fisherian deflation. As shown in figure 3, the three-standard-deviation shock (or 1.05 percent) causes inflation and output slump by more than 0.6 percent and 0.4 percent, respectively. To avoid such a catastrophic consequence, the key is to lower the real interest rate, which is needed to both stimulate aggregate demand and relax the financial constraint. In other words, there is no trade-off between inflation stability and financial stability. Here, the Ramsey planner imposes a higher labor tax rate to support inflation while the nominal interest rate is kept relatively stable. Since the financial constraint is not expected to be binding, the central bank takes this opportunity to reduce its holdings of private assets.

Before moving to consider policy implementation, I study a few more IRFs under different setups without showing the results. First, I ask how much the results so far depend on the government's access to fiscal and credit policy. I solve the partial Ramsey equilibrium with a fixed labor tax rate and only find minor welfare losses.

Without fiscal policy to help stabilize inflation, the contemporary response of monetary policy is more aggressive but the subsequent normalization is faster. Overall, monetary policy can still maneuver the real interest rate in a similar manner as in the full Ramsey equilibrium. On the other hand, the absence of credit policy yields large welfare losses[26] with significantly prolonged ZLB episodes (e.g., doubled under the financial shock) in order to relax the financial constraint. Second, it is interesting to examine how the government's past commitments restrict today's policy. An emphasis is put on the commitments to ease financial strains. To this aim, I consider IRFs from the stochastic steady state except that the multiplier associated with (12) is one-standard deviation lower (i.e., weaker commitment). The resulting nominal interest rate is uniformly higher than in the baseline case, which creates space for future monetary easing when the economy is more in need. The lack of monetary easing today is made up for by a larger asset purchase program and a higher tax rate to support inflation.

6. Simple Policy Rules

I now consider how to implement the Ramsey policy using a familiar set of simple rules as below:

$$\log \frac{R_t}{\bar{R}} = \max\left\{\kappa_R \log \frac{R_{t-1}}{\bar{R}} + \kappa_\Pi \log \frac{\Pi_t}{\bar{\Pi}} + \kappa_y \log \frac{y_t}{\bar{y}}, -\log \bar{R}\right\}, \tag{22}$$

$$\mathcal{P}_t = \kappa_{\mathcal{P}} \mathcal{P}_{t-1} + \kappa_{rr} \mathbb{E}_t(\log r_{k,t+1} - \log r_{t+1}), \tag{23}$$

where the credit rule is borrowed from Foerster (2015) and the five "κ"s are parameters searched numerically to maximize welfare.[27]

[26]This case is of less interest, since the central bank should always be able to coordinate credit and monetary policy.

[27]Note that the responses to inflation and output are not scaled by the degree of persistence $1-\kappa_R$. Moreover, a shadow interest rate R_t^* can be introduced into the monetary rule:

$$\log \frac{R_t^*}{\bar{R}} = \kappa_R \log \frac{R_{t-1}^*}{\bar{R}} + \kappa_\Pi \log \frac{\Pi_t}{\bar{\Pi}} + \kappa_y \log \frac{y_t}{y},$$

$$\log R_t = \max(0, \log R_t^*),$$

Table 3. Optimized Simple Rule

Shock	$\boldsymbol{\kappa_R}$	$\boldsymbol{\kappa_\Pi}$	$\boldsymbol{\kappa_y}$	$\boldsymbol{\kappa_\mathcal{P}}$	$\boldsymbol{\kappa_{rr}}$	$\boldsymbol{\lambda^c}$**(bps)**
Financial	1.1	3	0	0.9	5	0.013
Positive TFP	1.1	3	0	0.9	5	0.012
Negative TFP	1.0	3	0	0.9	5	0.014

Searching κ in a five-dimensional space is extremely costly with OBCs. To make the problem doable, I limit attention to a grid of the parameter space: $\kappa_R \in [0 : 0.1 : 3]$, $\kappa_\Pi \in [0 : 0.1 : 3]$, $\kappa_y \in [0 : 0.1 : 3]$, $\kappa_\mathcal{P} \in [0 : 0.1 : 1]$, $\kappa_{rr} \in [0 : 0.5 : 5]$, where the expression $[a : s : b]$ denotes the lower bound, the step, and the upper bound. For simplicity, I assume that the tax policy is unresponsive because adjusting taxes promptly is difficult. Admittedly, if (22) struggles to stabilize inflation, even a rather naive tax rule may improve welfare considerably. Nevertheless, a comprehensive study of optimal rules is left to future research. As shown shortly, the Taylor-type rule can do impressively well if equipped with somewhat unconventional parameters. To further ease the computational burden, I calculate welfare conditional on (i) state variables equal to the ergodic median of the Ramsey equilibrium under a fixed tax policy and (ii) one of the following shocks in the first period: a three-standard-deviation positive financial shock, a five-standard-deviation negative TFP shock, or a three-standard-deviation positive TFP shock. Welfare losses are measured in consumption equivalence λ^c implicitly defined by

$$\mathbb{W}_1\left(\{c_t^S - hc_{t-1}^S, l_t^S\}_{t\geq 1}\right) = \mathbb{W}_1\left(\{(1-\lambda^c)(c_t^R - hc_{t-1}^R, l_t^R\}_{t\geq 1}\right),$$

where $\mathbb{W}_1\left(\{c_t^R - hc_{t-1}^R, l_t^R\}_{t\geq 1}\right)$ is the welfare evaluated by the contingent plans for consumption and labor in the Ramsey equilibrium (also with a fixed labor tax) in period 1; $\mathbb{W}_1\left(\{c_t^S - hc_{t-1}^S, l_t^S\}_{t\geq 1}\right)$ is defined similarly for a given set of policy rules.[28]

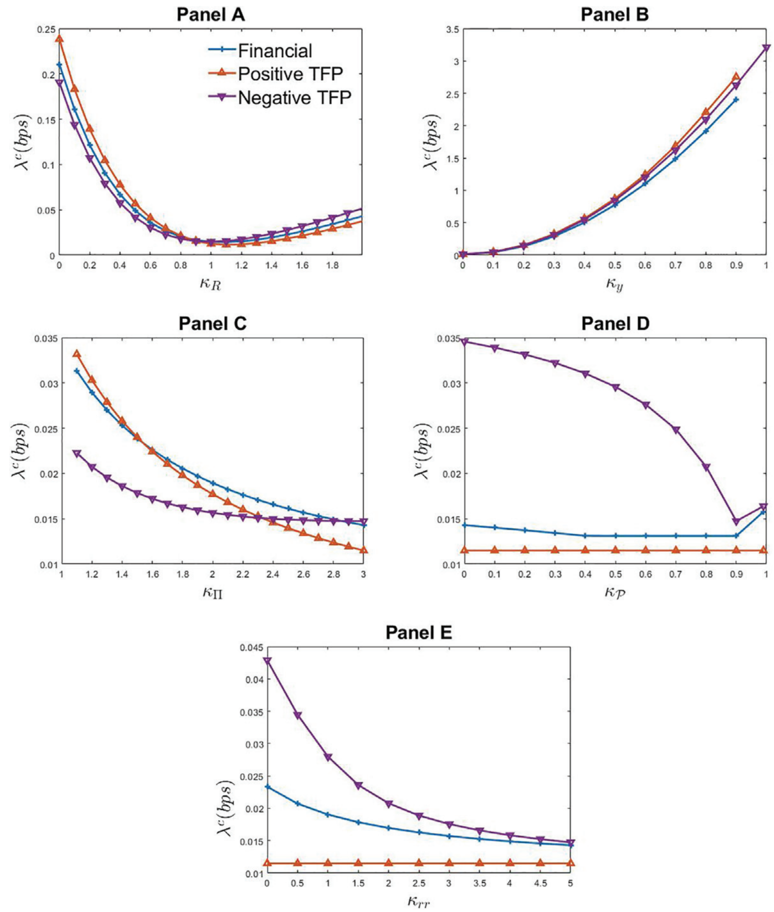
The optimized rules are reported in table 3 and the welfare surface near the optimal point is illustrated in figure 4. In all cases,

---

which is potentially welfare improving at the ZLB. The shadow rule does not change my results, because (22) rarely hits the ZLB regardless of its parameters.

[28]The utility function implies $\lambda^c = 1 - \left(\frac{\mathbb{W}_1^S + \mathbb{W}_1^{Rl}}{\mathbb{W}_1^{Rc}}\right)^{\frac{1}{1-\sigma}}$, where $\mathbb{W}_1^{Rc}$ and $\mathbb{W}_1^{Rl}$ are the discounted (dis)utility of consumption and labor, $\mathbb{W}_1^{Rc} - \mathbb{W}_1^{Rl} = \mathbb{W}_1^R$.

Figure 4. Welfare Losses Associated with Simple Rules Near the Optimal Point



Note: Parameters not shown on the x-axis are set to their optimal values.

the optimal parameters are essentially the same and the associated welfare losses are small.[29] The credit rule features a strong contemporary response to the credit spread with substantial persistence.

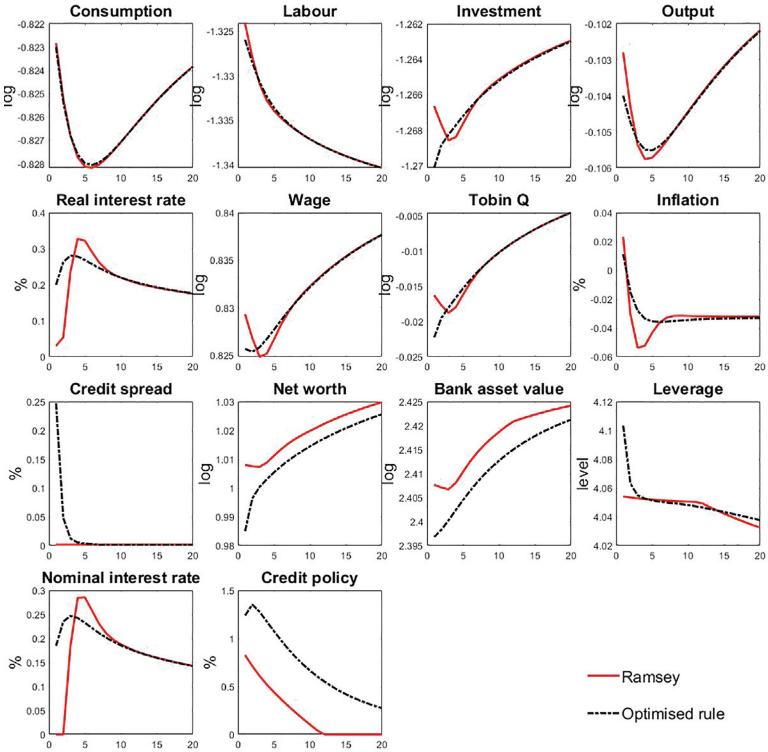
[29] $\kappa_\mathcal{P} \in [0.4, 0.9]$ yields virtually the same level of welfare under the TFP shock. I take $\kappa_\mathcal{P} = 0.9$ for consistency. The variation in κ_R across shocks is due to the fact that the parameter search is done over a grid. A finer search should reveal an optimal κ_R in the range of [1.0, 1.1].

While Foerster (2015) focuses more on extreme cases, i.e., $\kappa_{\mathcal{P}} = 0.99$ and $\kappa_{\mathcal{P}} = 0$, panel D of figure 4 shows that both are suboptimal. My results on the monetary rule echo a few findings in a standard New Keynesian model (Schmitt-Grohé and Uribe 2007), including a muted response to output and a strong response to inflation. The inflation coefficient reaches the upper bound of the search grid. But additional welfare gains from further increasing the inflation coefficient appear to be limited, especially when there is a trade-off between financial stability and inflation stability (i.e., under the financial shock and the negative TFP shock; see panel C of figure 4). The optimized monetary rule only differs from Schmitt-Grohé and Uribe (2007) in that the persistence coefficient exceeds but is close to 1, suggesting that the optimal monetary rule is forward looking and close to price-level targeting. This feature helps deal with the ZLB (Eggertsson and Woodford 2003)[30] without compromising the performance in normal times when the financial constraint and the ZLB are slack. As shown in Schmitt-Grohé and Uribe (2007), variations in the persistence coefficient affect welfare very little in normal times. Thus, my results should be robust to evaluations based on (computationally costly) unconditional welfare.

I now take a closer look at how the optimized rules respond to each shock. Upon a positive TFP shock, the simple-rule economy can largely replicate the Ramsey allocation. This is thanks to the strong response to inflation embedded in the monetary rule, which helps the economy avoid a binding financial constraint. Thus, the welfare gains of the optimized rule over the traditional Taylor rule are large, as the latter drives the economy into the spiral of Fisherian deflation (recall from subsection 5.2). On the other hand, under both the financial shock and the negative TFP shock, the government faces the trade-off between financial stability and inflation stability. To best illustrate this point, I show the simulated economy under the negative TFP shock, which raises both the credit spread and inflation. As shown in figure 5, the optimized rules prescribe too strong a credit intervention but insufficient monetary easing. The higher real interest rate in the

[30]The superinertial monetary policy also eliminates a equilibrium trapped permanently at the ZLB. See Sugo and Ueda (2008).

Figure 5. Simulation under the Optimized Rule and the Ramsey Policy



Note: The starting point of the simulation is the ergodic median of the Ramsey equilibrium except that TFP is five standard deviations below. The optimized rule contains the following parameters: $\kappa_R = 1.0, \kappa_\Pi = 3.0, \kappa_y = 0, \kappa_\mathcal{P} = 0.9, \kappa_{rr} = 5$.

simple-rule economy tightens the financial constraint. Given the positive credit spread, central bank asset purchases have a negative impact on bank net worth by crowding out banks from profitable investment opportunities.

There are potentially two simple ways of easing the policy tradeoff. For example, the government can use a tax policy to restrain inflation. Alternatively, the monetary rule can be augmented to respond to the credit spread.

7. Conclusion

I study optimal credit, monetary, and fiscal policy under commitment using a model that is as standard as possible, i.e., a New Keynesian model augmented with Gertler and Kiyotaki (2010) style financial frictions. The nonstandard part is that I allow two OBCs, one financial and one on the nominal interest rate. The model is solved in a way that captures the precautionary effects stemming from the nonlinearity of both OBCs, which has two important implications. First, credit policy is permanent in the risky steady state, despite being inactive in the deterministic steady state. Second, the government needs to avoid dual-binding constraints by keeping the nominal interest rate relatively high when the ZLB is not binding. I consider a financial shock and a TFP shock that generate a trade-off between inflation stability and financial stability even when policymakers have access to all the three policy instruments. The trade-off is found to be resolved in favor of financial stability with the credit spread staying virtually constant at its steady-state value under reasonable calibration. The optimal monetary policy is a counter to the conventional wisdom by suggesting that the nominal interest rate should respond negatively to a large negative productivity shock while its response to a positive productivity shock depends on how much the central bank is constrained by its past commitments. Finally, I find that optimized simple rules feature too-aggressive credit interventions and insufficient monetary easing relative to the Ramsey policy although the associated welfare losses are small.

Several important topics are not covered in this paper. First, the cost of credit policy is not fully captured by my model; see, for example, Borio and Zabai (2016) and Kandrac (2018). The recent work of Cui and Sterk (2018) suggests that credit policy is associated with considerable welfare costs in terms of inequality. Second, reserves in my model are treated as a perfect substitute for government bonds. However, there have been many papers (e.g., Christensen and Krogstrup 2017) studying imperfect asset substitutability and giving reserves a special role. Third, I leave a full investigation of simple and implementable policy rules to future research.

Appendix A. The Debt Ramsey Equilibrium

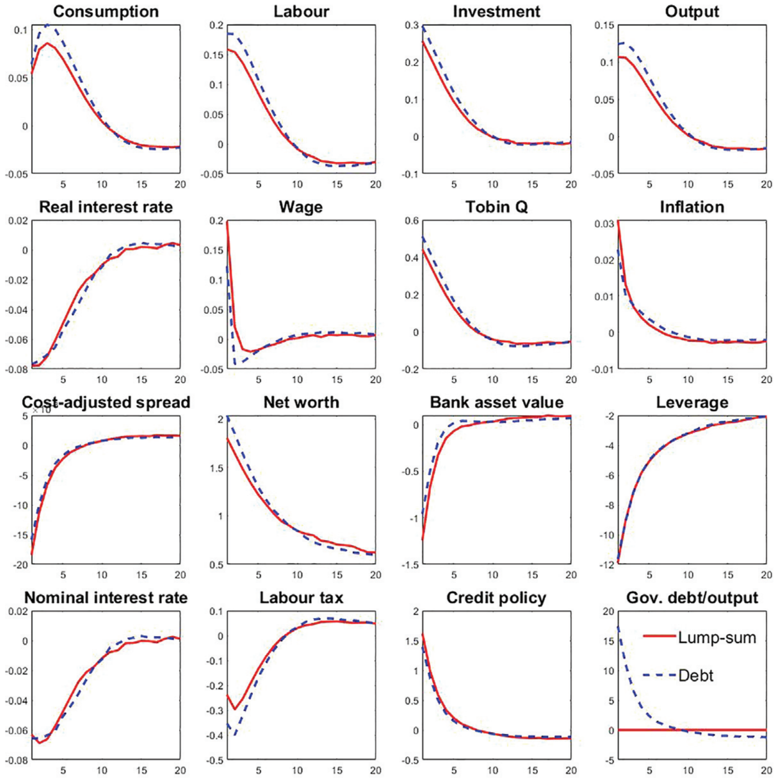
How does the government's asset purchase program affect its budget constraint? As the government issues government bonds (or reserves) to purchase private assets, the net gain of this operation is given by the credit spread. Recall that the credit spread is close to zero in the Ramsey equilibrium. The zero credit spread, together with the resource cost $\tau_{\mathcal{P}}(\mathcal{P}_t q_t s_t)^2$, means that the credit policy increases the fiscal burden although the effect might be quantitatively small. This adds interesting trade-offs to the policy problem but may not be true in reality.[31]

In the literature of optimal monetary and fiscal policy (e.g., Christiano, Chari, and Kehoe 1991; Schmitt-Grohé and Uribe 2004b; Siu 2004, among many others), the problem is how to finance an exogenous government spending shock. On the one hand, the government would like to smooth distortionary taxation by using unexpected inflation as a lump-sum tax on nominal wealth. On the other hand, the government would like to stabilize prices in the presence of nominal rigidity. This trade-off is found to be resolved in favor of price stability. In my model, however, public spending in the form of asset purchases is endogenous and the tax policy can adjust for reasons other than public finance.

Figures A.1 and A.2 show impulse responses of the lump-sum Ramsey equilibrium and the debt Ramsey equilibrium to shocks that trigger credit policy. The impulse responses are computed without burn-in to prevent the debt equilibrium from drifting too far away from the deterministic steady state. The cost-adjusted spread is the credit spread adjusted for the resource cost. Since credit policy generates incomes to finance itself, the debt level moves closely along the government's holding of private assets. The government budget constraint little changes the path of inflation but substantially changes the path of the tax rate. Hence, I conclude that the traditional trade-off between inflation stability and tax smoothing is still resolved in favor of the former. Particularly, high public debt does not make it difficult to raise interest rates, as Evans et al. (2015) suspect.

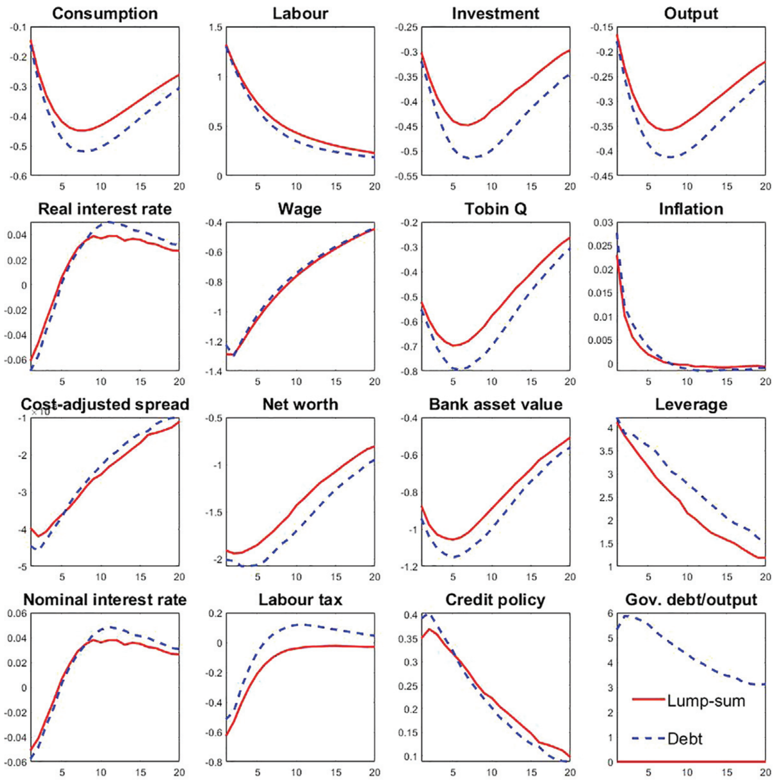
[31] See Reis (2016) for a discussion of this issue.

Figure A.1. Impulse Response to a Positive Financial Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

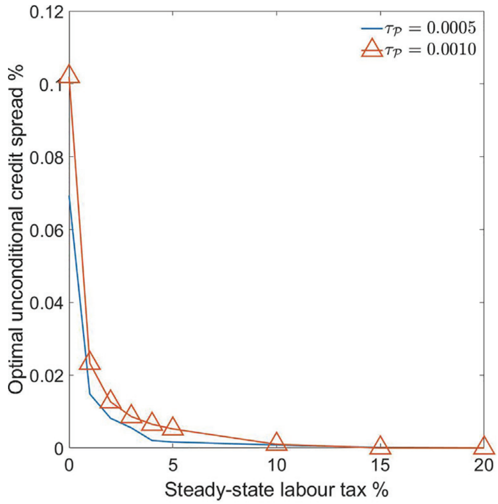
Figure A.2. Impulse Response to a Negative Financial Shock



Note: All variables are expressed in percentage-point deviations from their stochastic steady states. The size of the shocks is three standard deviations.

Appendix B. Additional Results

Figure B.1. Optimal Credit Spread and Steady-State Labor Tax



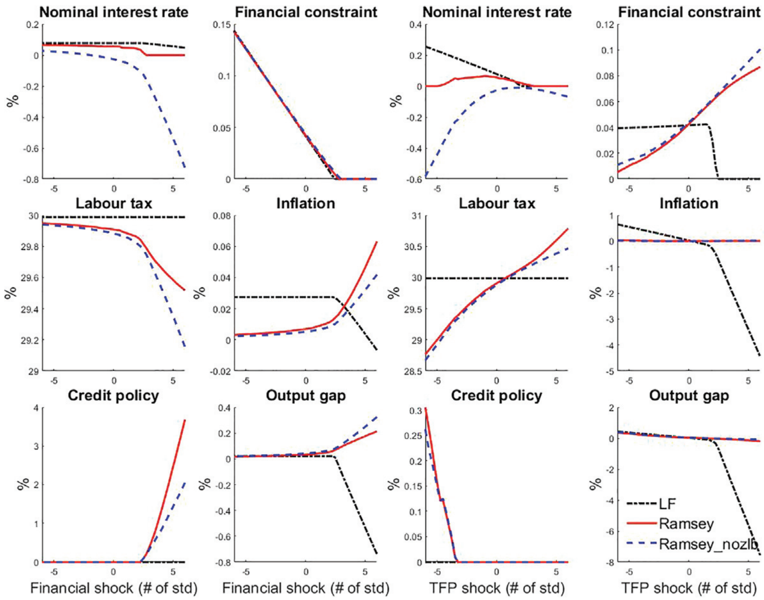
Note: This figure shows the unconditional mean of the credit spread in the Ramsey equilibrium when the steady-state labor tax is fixed at a given level.

Table B.1. Risky Steady States of the Ramsey and Laissez-Faire Equilibrium

	Log y_t	*Log* Π_t	*Log* R_t	*Spread*	ϕ_t	$\mathcal{P}_t$	$\tau_{w,t}$
Laissez-Faire							
Both OBCs	−10.38	0.03	0.15	0.04	4.00	0.00	29.99
FC Only	−9.96	0.03	0.13	0.00	3.96	0.00	29.99
ZLB Only	−11.47	−0.34	0.29	0.00	6.38	0.00	29.99
No OBC	−9.83	0.00	0.10	0.00	4.00	0.00	29.99
Ramsey							
Both OBCs	−9.64	0.02	0.14	0.00	4.02	1.85	29.91
FC Only	−9.80	0.00	0.08	0.00	3.91	0.21	29.98
ZLB Only	−9.81	0.00	0.09	0.00	3.98	0.00	29.99
No OBC	−9.82	0.00	0.10	0.00	3.99	0.00	29.99

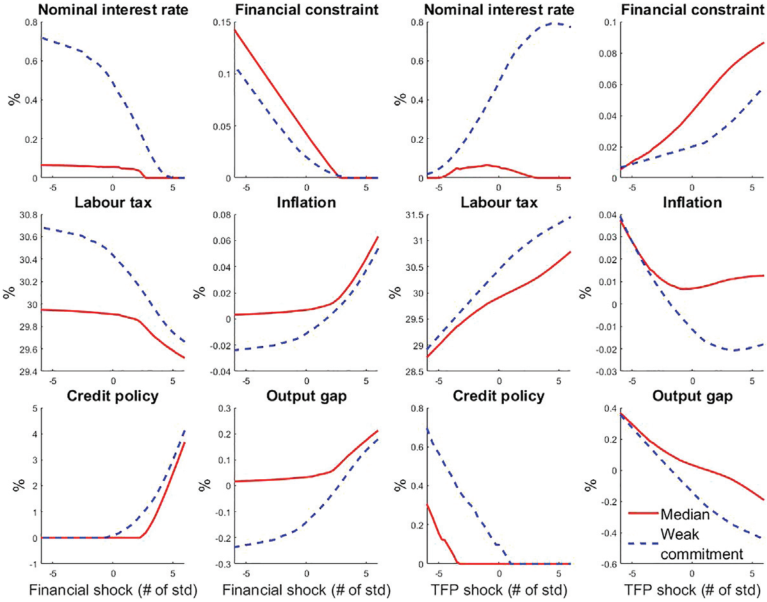
Note: Risky steady states are defined as in Coeurdacier, Rey, and Winant (2011). I calculate four RSSs based on the economy with none of the OBCs, one of the OBCs, or both of the OBCs, respectively. The log transformed variables are multiplied by 100; ratios and rates are in percentage points; the leverage is in level.

Figure B.2. Policy Functions in the Ramsey and Laissez-Faire Equilibrium



Note: Policy functions of key variables are plotted against either the financial or the productivity shock, while other state variables are set to their ergodic median in the Ramsey equilibrium. "LF" denotes the laissez-faire equilibrium. "Ramsey: no zlb" denotes the Ramsey equilibrium without the ZLB. The financial constraint is binding if it equals zero. The output gap is defined as deviations from the output level in the absence of both nominal rigidity and financial frictions.

Figure B.3. Policy Functions under Loose and Tight Commitment Constraint



Note: Policy functions of key variables are plotted against either the financial or the productivity shock, while other state variables are set to their ergodic median in the Ramsey equilibrium (red solid lines; for figures in color, see online version of paper at http://www.ijcb.org). Black dash-dotted lines are based on the same states except that the multiplier associated with (12) is one standard deviation below the median. The financial constraint is binding if it equals zero. The output gap is defined as deviations from the output level in the absence of both nominal rigidity and financial frictions.

References

Acharya, V. V., T. Eisert, C. Eufinger, and C. W. Hirsch. 2017. "Whatever It Takes: The Real Effects of Unconventional Monetary Policy."

Adam, K., and R. M. Billi. 2006. "Optimal Monetary Policy under Commitment with a Zero Bound on Nominal Interest Rates." *Journal of Money, Credit and Banking* 38 (7): 1877–1905.

Adjemian, S., and M. Juillard. 2013. "Stochastic Extended Path Approach." Unpublished Manuscript.

Alessandri, P., and B. D. Nelson. 2015. “Simple Banking: Profitability and the Yield Curve.” *Journal of Money, Credit and Banking* 47 (1): 143–75.

Altavilla, C., F. Canova, and M. Ciccarelli. 2016. “Mending the Broken Link: Heterogeneous Bank Lending and Monetary Policy Pass-through.”

Benigno, P., G. B. Eggertsson, and F. Romei. 2020. “Dynamic Debt Deleveraging and Optimal Monetary Policy.” *American Economic Journal: Macroeconomics* 12 (2): 310–50.

Benigno, P., and S. Nisticò. 2020. “Non-neutrality of Open-market Operations.” *American Economic Journal: Macroeconomics* 12 (3): 175–226.

Bernanke, B. S. 2017. “Monetary Policy in a New Era.”

Bianchi, J. 2016. “Efficient Bailouts?” *American Economic Review* 106 (12): 3607–59.

Bocola, L. 2016. “The Pass-through of Sovereign Risk.” *Journal of Political Economy* 124 (4): 879–926.

Bordalo, P., N. Gennaioli, and A. Shleifer. 2018. “Diagnostic Expectations and Credit Cycles.” *Journal of Finance* 73 (1): 199–227.

Borio, C., and A. Zabai. 2016. “Unconventional Monetary Policies: A Re-appraisal.” BIS Working Paper No. 570.

Brunnermeier, M. K., and Y. Koby. 2017. “The Reversal Interest Rate: An Effective Lower Bound on Monetary Policy.”

Brunnermeier, M. K., and Y. Sannikov. 2016. “The I Theory of Money.” NBER Working Paper No. 22533.

Cahn, C., J. Matheron, and J.-G. Sahuc. 2017. “Assessing the Macroeconomic Effects of LTROs during the Great Recession.” *Journal of Money, Credit and Banking* 49 (7): 1443–82.

Calvo, G. A. 1983. “Staggered Prices in a Utility-Maximizing Framework.” *Journal of Monetary Economics* 12 (3): 383–98.

Carrillo, J. A., E. G. Mendoza, V. Nuguer, and J. Roldán-Peña. 2017. “Tight Money-Tight Credit: Coordination Failure in the Conduct of Monetary and Financial Policies.” NBER Working Paper No. 23151.

Caruso, A., L. Reichlin, and G. Ricco. 2018. “Financial and Fiscal Interaction in the Euro Area Crisis: This Time was Different.”

Cavallino, P., and D. Sandri. 2019. “The Expansionary Lower Bound: Contractionary Monetary Easing and the Trilemma.” BIS Working Paper No. 770.

Chakraborty, I., I. Goldstein, and A. MacKinlay. 2017. "Monetary Stimulus and Bank Lending."

Christensen, J. H. E., and S. Krogstrup. 2017. "A Portfolio Model of Quantitative Easing." Working Paper No. 2016-12, Federal Reserve Bank of San Francisco.

Christensen, J. H. E., and G. D. Rudebusch. 2012. "The Response of Interest Rates to US and UK Quantitative Easing." *Economic Journal* 122 (564): F385–F414.

Christiano, V. V., L. J. Chari, and P. J. Kehoe. 1991. "Optimal Fiscal and Monetary Policy: Some Recent Results." *Journal of Money, Credit and Banking* 23 (3): 519–39.

Coeurdacier, N., H. Rey, and P. Winant. 2011. "The Risky Steady State." *American Economic Review* 101 (3): 398–401.

Cui, W., and V. Sterk. 2018. "Quantitative Easing." Discussion Paper No. 1830, Centre for Macroeconomics (CFM).

Curdia, V., and M. Woodford. 2010. "Credit Spreads and Monetary Policy." *Journal of Money, Credit and Banking* 42 (s1): 3–35.

Dedola, L., P. Karadi, and G. Lombardo. 2013. "Global Implications of National Unconventional Policies." *Journal of Monetary Economics* 60 (1): 66–85.

Dedola, L., and G. Lombardo. 2012. "Financial Frictions, Financial Integration and the International Propagation of Shocks." *Economic Policy* 27 (70): 319–59.

Del Negro, M., G. Eggertsson, A. Ferrero, and N. Kiyotaki. 2017. "The Great Escape? A Quantitative Evaluation of the Fed's Liquidity Facilities." *American Economic Review* 107 (3): 824–57.

Del Negro, M., R. B. Hasegawa, and F. Schorfheide. 2016. "Dynamic Prediction Pools: An Investigation of Financial Frictions and Forecasting Performance." *Journal of Econometrics* 192 (2): 391–405.

Del Negro, M., and C. A. Sims. 2015. "When Does a Central Bank's Balance Sheet Require Fiscal Support?" *Journal of Monetary Economics* 73 (July): 1–19.

Eggertsson, G. B., and P. Krugman. 2012. "Debt, Deleveraging, and the Liquidity Trap: A Fisher-Minsky-Koo Approach." *Quarterly Journal of Economics* 127 (3): 1469–1513.

Eggertsson, G. B., and M. Woodford. 2003. "Optimal Monetary Policy in a Liquidity Trap." NBER Working Paper No. 9968.

Evans, C., J. Fisher, F. Gourio, and S. Krane. 2015. “Risk Management for Monetary Policy Near the Zero Lower Bound.” *Brookings Papers on Economic Activity* 46 (1, Spring): 141–219.

Foerster, A. T. 2015. “Financial Crises, Unconventional Monetary Policy Exit Strategies, and Agents’ Expectations.” *Journal of Monetary Economics* 76 (November): 191–207.

Gagnon, J., M. Raskin, J. Remache, and B. Sack. 2011. “The Financial Market Effects of the Federal Reserve’s Large-scale Asset Purchases.” *International Journal of Central Banking* 7 (1, March): 3–43.

Gertler, M., and P. Karadi. 2011. “A Model of Unconventional Monetary Policy.” *Journal of Monetary Economics* 58 (1): 17–34.

Gertler, M., and N. Kiyotaki. 2010. “Financial Intermediation and Credit Policy in Business Cycle Analysis.” *Handbook of Monetary Economics,* Vol. 3, ed. B. M. Friedman and M. Woodford, 547–99 (chapter 11). North-Holland.

Guerrieri, L., and M. Iacoviello. 2015. “OccBin: A Toolkit for Solving Dynamic Models with Occasionally Binding Constraints Easily.” *Journal of Monetary Economics* 70 (March): 22–38.

Harrison, R. 2017. “Optimal Quantitative Easing.” Working Paper No. 678, Bank of England.

Holden, T. D. 2016. “Computation of Solutions to Dynamic Models with Occasionally Binding Constraints.”

———. 2019. “Existence and Uniqueness of Solutions to Dynamic Models with Occasionally Binding Constraints.” Kiel, Hamburg: ZBW Leibniz Information Centre for Economics.

Holston, K., T. Laubach, and J. C. Williams. 2017. “Measuring the Natural Rate of Interest: International Trends and Determinants.” *Journal of International Economics* 108 (Supplement 1): S59–S75.

Ivashina, V., and D. Scharfstein. 2010. “Bank Lending during the Financial Crisis of 2008.” *Journal of Financial Economics* 97 (3): 319–38.

Jensen, H., I. Petrella, S. H. Ravn, and E. Santoro. 2020. “Leverage and Deepening Business-Cycle Skewness.” *American Economic Journal: Macroeconomics* 12 (1): 245–81.

Jermann, U., and V. Quadrini. 2012. “Macroeconomic Effects of Financial Shocks.” *American Economic Review* 102 (1): 238–71.

Jiao, Y. 2019. "Financial Crises, Bailouts and Monetary Policy in Open Economies."

Joyce, M., A. Lasaosa, I. Stevens, and M. Tong. 2011. "The Financial Market Impact of Quantitative Easing in the United Kingdom." *International Journal of Central Banking* 7 (3, September): 113–61.

Kandrac, J. 2018. "The Cost of Quantitative Easing: Liquidity and Market Functioning Effects of Federal Reserve MBS Purchases." *International Journal of Central Banking* 14 (5, December): 259–304.

Koop, G., M. H. Pesaran, and S. M. Potter. 1996. "Impulse Response Analysis in Nonlinear Multivariate Models." *Journal of Econometrics* 74 (1): 119–47.

Krishnamurthy, A., and A. Vissing-Jorgensen. 2011. "The Effects of Quantitative Easing on Interest Rates: Channels and Implications for Policy." NBER Working Paper No. 17555.

López-Salido, D., J. C. Stein, and E. Zakrajŝek. 2017. "Credit-market Sentiment and the Business Cycle." *Quarterly Journal of Economics* 132 (3): 1373–1426.

Maliar, L., and S. Maliar. 2015. "Merging Simulation and Projection Approaches to Solve High-dimensional Problems with an Application to a New Keynesian Model." *Quantitative Economics* 6 (1): 1–47.

Nakov, A. 2008. "Optimal and Simple Monetary Policy Rules with Zero Floor on the Nominal Interest Rate." *International Journal of Central Banking* 4 (2, July): 73–127.

Oh, H., and R. Reis. 2012. "Targeted Transfers and the Fiscal Response to the Great Recession." *Journal of Monetary Economics* 59 (Supplement): S50–S64.

Perri, F., and V. Quadrini. 2018. "International Recessions." *American Economic Review* 108 (4–5): 935–84.

Quint, M. D., and M. P. Rabanal. 2017. "Should Unconventional Monetary Policies Become Conventional?" International Monetary Fund.

Reifschneider, D., and J. C. Williams. 2000. "Three Lessons for Monetary Policy in a Low-inflation Era." *Journal of Money, Credit and Banking* 32 (4): 936–66.

Reis, R. 2016. "Can the Central Bank Alleviate Fiscal Burdens?" NBER Working Paper No. 23014.

Romer, C. D., and D. H. Romer. 2017. "New Evidence on the Aftermath of Financial Crises in Advanced Countries." *American Economic Review* 107 (10): 3072–3118.

Schmitt-Grohé, S., and M. Uribe. 2004a. "Optimal Fiscal and Monetary Policy under Imperfect Competition." *Journal of Macroeconomics* 26 (2): 183–209.

———. 2004b. "Optimal Fiscal and Monetary Policy under Sticky Prices." *Journal of Economic Theory* 114 (2): 198–230.

———. 2007. "Optimal Simple and Implementable Monetary and Fiscal Rules." *Journal of Monetary Economics* 54 (6): 1702–25.

Schularick, M., and A. M. Taylor. 2012. "Credit Booms Gone Bust: Monetary Policy, Leverage Cycles, and Financial Crises, 1870-2008." *American Economic Review* 102 (2): 1029–61.

Siu, H. E. 2004. "Optimal Fiscal and Monetary Policy with Sticky Prices." *Journal of Monetary Economics* 51 (3): 575–607.

Smets, F., and R. Wouters. 2007. "Shocks and Frictions in US Business Cycles: A Bayesian DSGE Approach." *American Economic Review* 97 (3): 586–606.

Sugo, T., and K. Ueda. 2008. "Eliminating a Deflationary Trap through Superinertial Interest Rate Rules." *Economics Letter*s 100 (1): 119–22.

Svensson, L. E. O. 2019. "Monetary Policy Strategies for the Federal Reserve."

Swarbrick, J., T. Holden, and P. Levine. 2017. "Credit Crunches from Occasionally Binding Bank Borrowing Constraints."

Woodford, M. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton University Press.

The Role of Expectations in Changed Inflation Dynamics*

Damjan Pfajfar and John M. Roberts
Federal Reserve Board

The Phillips curve has been much flatter in the past 20 years than in the preceding decades. We consider two hypotheses. One is that prices at the microeconomic level are stickier than they used to be. The other is that expectations of firms and households about future inflation are now less well informed by macroeconomic conditions. We use inflation expectations from surveys to help distinguish between our two hypotheses empirically. We find that reduced attentiveness can, in some cases, account for three-fourths of the reduction in the sensitivity of inflation to economic conditions in recent decades.

JEL Codes: E31, E37.

1. Introduction

As many authors have noted, the Phillips curve is much flatter than it used to be; a sampling includes Atkeson and Ohanian (2001), Roberts (2006), Mavroeidis, Plagborg-Møller, and Stock (2014), and Blanchard (2016). We explore two hypotheses about the origin of the

*We would like to thank the editor Boragan Aruoba for his comments and for sharing his ATSIX data. We would also like to thank two anonymous referees, Fernanda Nechio, Sergey Slobodyan, and Ed Knotek for their comments. In addition, we would like to thank seminar participants at Federal Reserve Board, IAAE 2018 Annual Conference, System Macro Meetings at the Federal Reserve Bank of San Francisco, 2019 CEBRA conference in New York, 2019 CFE conference in London, and Bank of Russia Conference Inflation: New Insights for Central Banks for their comments. Kevin Starnes and Samuel Messer provided excellent research assistance. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Federal Reserve Board. Author contact: Board of Governors of the Federal Reserve System, 2000 Constitution Avenue NW, Washington, DC 20551, U.S.A. E-mail: damjan.pfajfar@frb.gov and john.m.roberts@frb.gov. Website: https://sites.google.com/site/dpfajfar/ and https://www.federalreserve.gov/econres/john-m-roberts.htm.

flatter Phillips curve. One is that prices at the firm level are "stickier" than in the past. Ball, Mankiw, and Romer (1988), for example, argued that lower inflation would lead to less-frequent adjustment of prices; because inflation has been lower in the past 20 years than in the decades before, we would expect less-frequent price adjustment and therefore, in the logic of sticky-price models, a flatter Phillips curve. The other conjecture is that firms and households pay less attention to macroeconomic conditions when setting wages and prices now than in the past. This conjecture was articulated in 2001 by then Federal Reserve Chairman Alan Greenspan, who expressed the hope that lower inflation would imply less of a need for firms and households to pay attention to inflation in making their economic decisions.[1] Although Greenspan did not express his hypothesis this way, it is similar in spirit to the rational inattention hypothesis of Sims (2003), who argued that when an economic decision becomes less salient, rational agents with limited bandwidth will devote less attention to it.

We document that from the perspective of the New Keynesian Phillips curve under model-consistent expectations, the sensitivity of inflation to economic activity has been markedly lower in the period starting 1997 than in the preceding two decades. When interpreted through the lens of the canonical Calvo model of staggered price setting, the frequency of price change fell dramatically. While Nakamura et al. (2018) document some reduction in the frequency of price change at the firm level, a much greater increase in nominal rigidity would be needed to account for the change in the slope of the New Keynesian Phillips curve found when the possibility of inattention is not entertained.

Central to our efforts to distinguish between our two main hypotheses, we bring to bear information on inflation expectations taken from surveys. As a number of authors (Roberts 1997; Mavroeidis, Plagborg-Møller, and Stock 2014; Fuhrer 2017; Coibion, Gorodnichenko, and Kamdar 2018) argue, survey measures of inflation expectations bring valuable additional information to the empirical analysis of aggregate inflation. In particular, Coibion,

[1] "Price stability is best thought of as an environment in which inflation is so low and stable over time that it does not materially enter into the decisions of households and firms" (Greenspan 2001).

Gorodnichenko, and Kamdar (2018) find that the coefficients of a reduced-form Phillips curve shift very little when the estimation is conditioned on household inflation expectations. Roth (2013) also finds little evidence of important shifts in Phillips-curve parameters when conditioned on survey expectations. Roberts (1997) and Fuhrer (2017) argue that the excessive persistence of survey forecasts helps explain inflation dynamics in a structural model. At the same time, Dräger and Lamla (2012), Coibion et al. (2018), and Mertens and Nason (2018) have argued that survey expectations in the past two/three decades have become less responsive to macroeconomic developments.[2] Furthermore, Dräger and Lamla (2018) and Eusepi et al. (2019) point out that after 1996, inflation expectations became more anchored. Our premise is that if survey forecasts are less responsive to economic conditions now than before, and if the inflation process involves expectations that depart from the simple benchmark of model-consistent expectations, then it stands to reason that a misspecified Phillips curve estimated assuming simple model-consistent expectations (MCE) would spuriously indicate that the Phillips curve has flattened in recent years.

We find that, across surveys and time periods, survey measures of inflation expectations react more sluggishly than the simple MCE benchmark would predict. These results are similar to those of Carroll (2003), Coibion et al. (2018), and Mertens and Nason (2018), who also find that expectations as captured by surveys adjust sluggishly.

Results on our central hypothesis are sensitive to the measure of inflation expectations. We find a large reduction in attentiveness across our two subsamples with the University of Michigan's survey of household inflation expectations. Based on the estimates of our model using the Michigan survey as an indicator of expectations, we find that a reduction in attentiveness can account for 75 percent of the reduction in the reduced-form sensitivity of inflation to an identified aggregate demand shock. The remaining 25 percent is explained by changes in the coefficients of the New Keynesian Phillips curve

[2] It could be argued that this is due to increased credibility of central banks. Christelis et al. (2016) and Lamla, Pfajfar, and Rendell (2019) study the relationship between confidence (trust) in the central bank and inflation expectations.

that is part of our structural model, which would reflect changes in the frequency of price change.

When we examine surveys of forecasters, such as the Survey of Professional Forecasters (SPF), we do not find the same sharp change in behavior evident in the Michigan survey. Participants in the SPF appear to be about equally attentive in the two periods we examine, and, conditional on that roughly constant degree of attentiveness, the reduction in the slope of the New Keynesian Phillips curve is about as large as in the estimates assuming model-consistent expectations. It is thus only for the Michigan survey of households that we find support for the Greenspan (2001) conjecture that firms and households would become less attentive in the formation of their expectations of inflation. It is possible that the Michigan survey results present a more accurate picture of the changes in the economy. Coibion and Gorodnichenko (2015b), for example, argue that household expectations may be closer to those of actual decision-makers than are forecasts from economists (such as the SPF) and thus that results based on the Michigan survey should be favored.

Ball and Mazumder (2011, 2019) also study the stability of the Phillips curve.[3] Like us, Ball and Mazumder (2011) posit that changes in the frequency of price adjustment and in expectations formation may have played a role in explaining the shift in Phillips-curve parameters. Ball and Mazumder (2011), however, only look at reduced-form evidence and they do not examine measures of expectations.[4] As a consequence, they are not able to distinguish the contribution of expectations formation to the flattening of the Phillips curve from other factors, such as the frequency of price change. By introducing survey measures of expectations into a structural model that considers inflation and expectations formation jointly, we are able to evaluate the contribution of each factor to the changes in the sensitivity of inflation to economic activity.

[3] As do many other authors, Ball and Mazumder (2011) find a break in the parameters of a reduced-form Phillips curve—in their case, in 1985. Ball and Mazumder (2019) argue that the Phillips curve has been stable since 1985. Dräger and Lamla (2018) and Eusepi et al. (2019), however, show that there was a break in anchoring of inflation expectations around 1996, after the preemptive tightening by the Greenspan-era Federal Open Market Committee.

[4] Ball and Mazumder (2019) consider long-run inflation expectations from the SPF to inform the level at which inflation expectations are anchored.

We cross-check our findings with results from microeconomic studies. Until recently, the available evidence had suggested that, at levels of inflation that have prevailed in the United States, there had been little variation in the frequency of prices change. That was the conclusion, for example, of Bils and Klenow (2004) and Nakamura and Steinsson (2008) in the United States. Examining Mexican data, Gagnon (2009) concluded that at very high levels of inflation (above 15 percent), the frequency of price change was sensitive to the prevailing rate of inflation, but that at levels of inflation below the 10 to 15 percent range (which is at the high end of the U.S. inflation experience), there was little sensitivity of the frequency of price change to inflation. Additional data collected by Nakamura et al. (2018), however, shows that in the late 1970s and early 1980s—a period of relatively high inflation in the United States—firms changed prices more frequently than in the subsequent period. We explore the potential macroeconomic implications of the changes in the price-change frequency documented by Nakamura et al. (2018). As we noted earlier, while we find that this microeconomic evidence predicts some reduction in the slope of the Phillips curve, it cannot fully account for the very large reduction we find in the conventional New Keynesian Phillips curve estimated under model-consistent expectations.

Mavroeidis, Plagborg-Møller, and Stock (2014) conduct an extensive analysis attempting to relate inflation, inflation expectations, and measures of economic activity from a single-equation perspective. Their conclusions are pessimistic: They find that it is not possible to estimate both the relationship between inflation and economic activity and the degree of forward-looking behavior. While their results are somewhat stronger when they introduce survey measures of expectations, they still were not able to estimate the key parameters of interest with any precision.

The questions we address are similar to those of Mavroeidis, Plagborg-Møller, and Stock (2014), and their results suggest that we are entering treacherous waters. However, our focus is different from theirs. Both our work and theirs assess the empirical validity of the canonical hybrid New Keynesian Phillips curve with model-consistent expectations. The specific question of Mavroeidis, Plagborg-Møller, and Stock (2014) is whether expectations belong in a structural model of inflation. They conclude that there is not enough information in the macro data to permit an answer to that question. We instead assume that expectations belong in the structural model of inflation, as in the canonical New Keynesian Phillips curve. But we do not require those expectations to obey the simple MCE benchmark, and we ask to what extent these expectations may differ from that benchmark. Perhaps most importantly, our full-system estimation, in which we use information on both expectations and inflation to inform the structural relationship between economic activity and inflation, allows us to identify separately the degree of the departure from the MCE benchmark as well as the impact of economic activity on inflation conditional on expectations.

2. Theory

2.1 Model

We'll first lay out our model of expectations formation. We designate inflation by Δp_t, and $E_t\Delta p_{t+1}$ represents the expectations of agents setting prices. It is typically assumed that expectations are model consistent. In that case,

$$E_t\Delta p_{t+1} = M_t\Delta p_{t+1}, \tag{1}$$

where $M_t\Delta p_{t+1}$ represents model-consistent expectations.[5] We explore two departures from the simplest version of model-consistent expectations based on informational frictions.[6] The first is motivated by the rational inattention model of Sims (2003). In Sims's model, agents receive only a noisy signal of (future) inflation. Thus, we assume that agents' expectations will be related to the true, model-consistent expectations by

$$E_t\Delta p_{t+1} = \mu M_t\Delta p_{t+1}, \tag{2}$$

[5] By "model-consistent expectations," we mean expectations based on the full structure of the model, including knowledge of all the parameters and contemporaneous shocks of the model. These expectations will be unbiased predictors of inflation.

[6] See Coibion, Gorodnichenko, and Kamdar (2018) for a comparison of informational frictions with other departures from full-information rational expectations.

where $0 \leq \mu \leq 1$. That is, agents' actual expectations move only partially with the ideal, model-consistent expectations. In Sims's model, it is costly for agents to pay attention to the future course of inflation. With greater effort, agents can improve the quality of their inflation forecasts, raising the value of μ. With sufficient effort, expectations will be close to the MCE benchmark and the value of μ will approach 1.

Another hypothesis about expectations formation we consider is related to the epidemiological model of Carroll (2003):

$$E_t \Delta p_{t+1} = (1 - \lambda) M_t \Delta p_{t+1} + \lambda E_{t-1} \Delta p_t. \tag{3}$$

Under Carroll's hypothesis, expectations adjust only gradually toward a well-informed value.[7] When agents learn right away about model-consistent expectations, $\lambda = 0$.

We nest these two conjectures about expectations formation to obtain

$$E_t \Delta p_{t+1} = \mu M_t \Delta p_{t+1} + \lambda E_{t-1} \Delta p_t. \tag{4}$$

The key parameter controlling the degree of attentiveness is μ: If μ is smaller, the fully informed expectational benchmark, $M_t \Delta p_{t+1}$, plays a smaller role in the determination of inflation expectations. Conditional of the value of μ, the coefficient λ determines the extent to which expectations eventually adjust to the fully informed benchmark. Under Carroll's model, $\mu + \lambda = 1$, and if $M_t \Delta p_{t+1}$ were to remain stable, $E_t \Delta p_{t+1}$ would eventually move to it.

In our empirical model of expectations formation, we consider two sources of error in survey expectations. One is measurement error, which will affect inflation expectations but not actual inflation. One potential source of measurement error is sampling error.[8]

[7] Carroll (2003) assumes that expectations of households gradually converge toward expectations of professional forecasters. We instead assume that expectations gradually converge to their model-consistent value. In this sense the specification is more similar to Pfajfar and Zakelj (2014), as the expectations gradually converge to MCE forecast. Coibion and Gorodnichenko (2015a) consider a similar model for the evolution of expectations, Equation 3, p. 2649. The main difference with Carroll's model concerns the final term, which in Coibion and Gorodnichenko's model is $\lambda E_{t-1} \Delta p_{t+1}$. Carroll (2003) provides conditions under which it is appropriate to use a specification such as our Equation (3).

[8] Sampling error is a significant issue in the Michigan Survey of Consumers, as the divergence of views about future inflation across households is very wide.

In addition, survey respondents may report a different number to the survey taker than they use when they actually make decisions (for example, they may report a rounded number; see Binder 2017). This latter source of error could become larger when survey respondents are less attentive.

We also allow for a structural shock to expectations, which, through its impact on expectations, can also affect actual inflation. We interpret this structural shock to expectations as a kind of sunspot, in line with Lubik and Schorfheide (2004), who suggest that an error in expectations that has implications for actual inflation can be interpreted as a sunspot. Thus, our model allows for survey measures to be affected by both sunspots and measurement error, and these innovations are distinguished by their effects on inflation: Measurement error affects the measure of expectations only, whereas the sunspot affects both expectations and actual inflation.

Putting together these various elements gives us our empirical model for survey measures of inflation expectations:

$$E_t \Delta p_{t+1} = \mu M_t \Delta p_{t+1} + \lambda E_{t-1} \Delta p_t + \nu_t, \tag{5}$$

$$S_t \Delta p_{t+1} = E_t \Delta p_{t+1} + u_t, \tag{6}$$

$$u_t = \rho_u u_{t-1} + \omega_t, \tag{7}$$

where $S_t \Delta p_{t+1}$ is the survey measure of expectations. Equation (5) generalizes Equation (4) to allow for a structural shock to expectations, ν. Equation (6) allows for measurement error in survey measures of expectations, and the specification in Equation (7) allows that measurement error to be serially correlated.[9]

Our empirical model of inflation is the hybrid New Keynesian Phillips curve that has been used widely:

$$\Delta p_t - \gamma \Delta p_{t-1} = \beta(E_t \Delta p_{t+1} - \gamma \Delta p_t) + \kappa y_t + \epsilon_t, \tag{8}$$

[9]Melosi (2016) also uses survey expectations as an observable to help identify a structural model of inflation expectations. Melosi (2016), however, uses a different structural model than we do, based on imperfect common knowledge. Fuhrer (2017) includes survey expectations as an observable in a structural macroeconomic model but in a reduced-form fashion; he does not specify a structural model for expectations. Neither paper addresses the possible contribution of changes in expectations formation to the flattening of the Phillips curve.

where y_t is the output gap. As discussed in, for example, Calvo (1983) and Woodford (2003), the parameter κ is related to the frequency of price change: The less frequently prices are changed, the smaller κ will be. Thus, a flattening of the Phillips curve caused by less-frequent price change would manifest as a smaller value of κ. Following the empirical literature (for example, Galí and Gertler 1999 and Christiano, Eichenbaum, and Evans 2005), we allow for partial indexation to lagged inflation.[10]

We complete our model with a reduced-form model of the output gap:

$$y_t = \phi_1 y_{t-1} + \phi_2 y_{t-2} + \phi_3 \Delta p_{t-1} + \phi_4 \Delta p_{t-2} + \eta_t. \tag{9}$$

This specification allows the lagged inflation gap to capture the empirical regularity of some predictive power of lagged inflation for the output gap. We would expect ϕ_3 and ϕ_4 to be less than zero, reflecting the effect of tighter monetary policy in response to inflation shocks.[11]

We assume that the shocks to the model—ν, ω, ϵ, and η—are mutually uncorrelated white noise. The assumption that survey measurement error is unrelated to the other shocks should be relatively uncontroversial—indeed, that is essentially the definition of measurement error. In addition, we allow for an additional source of variation in expectations that is, effectively, correlated with movements in inflation: the structural expectations shock, ν. The assumption that

[10]Mavroeidis, Plagborg-Møller, and Stock (2014) argue that if we take literally the microfoundations of the New Keynesian Phillips curve, it is inappropriate to use survey expectations in Equation (8). However, Adam and Padula (2011) show that in certain cases, survey expectations can be used. Because our model is more complex than the case Adam and Padula (2011) consider, it is an open question whether their result applies in our case.

[11]Many New Keynesian models make the output gap a function of the real interest rate and include a monetary policy reaction function. We do not take this approach, because the U.S. economy has spent a substantial fraction of the time during our sample period at the effective lower bound (ELB) for nominal interest rates. Taking due account of the ELB would introduce considerable complication and would require taking stands on controversial topics such as the effect of forward guidance and the degree to which asset purchase programs were an adequate substitute for conventional monetary policy. Because our interest is in the inflation process, all that is needed is a simple forecasting equation for the output gap, and we believe Equation (9) serves that role well.

this shock is uncorrelated with the shock to the structural Phillips curve is essentially true by definition—the structural expectations shock is intended to reflect movements in expectations that are not related to other shocks affecting the economy. Moreover, because this shock is allowed to affect inflation simultaneously, the assumption of orthogonality is not restrictive.

Specifically, we assume that the Phillips curve and aggregate demand shocks (ϵ and η) are not correlated. Thus, we assume that the shock in the Phillips curve does not affect output contemporaneously but will affect the output gap through the lags of inflation in the output gap equation. We address the possibility of contemporaneous correlation with two different exercises in the robustness section (Section 5).

2.2 An Illustrative Model Solution

In this subsection, we use a simplified version of our model to illustrate how, in the absence of information on expectations, it can be difficult to distinguish a reduction in nominal rigidity from a reduction in attentiveness. Let's assume that expectations are formed according to Sims's rational inattention model, as in Equation (2). Suppose further that inflation is determined according to a simplified version of the New Keynesian Phillips curve, without indexation. In that case, our models for inflation and expectations are

$$E_t \Delta p_{t+1} = \mu M_t \Delta p_{t+1} \tag{10}$$

$$\Delta p_t = \beta E_t \Delta p_{t+1} + \kappa y_t + \epsilon_t. \tag{11}$$

If we substitute Equation (10) into Equation (11), we obtain

$$\Delta p_t = \beta \mu M_t \Delta p_{t+1} + \kappa y_t + \epsilon_t. \tag{12}$$

Equation (12) can be referred to as the "discounted" New Keynesian Phillips curve, in analogy to the "discounted Euler equation" proposed by McKay, Nakamura, and Steinsson (2016, 2017) (see also Gabaix 2017).

To aid in developing intuition about the possible implications of noisy expectations for empirical estimates of the slope of the Phillips curve, it is instructive to assume a simple AR(1) process for the output gap:

$$y_t = \rho y_{t-1} + \zeta_t. \tag{13}$$

With this assumption, Equation (12) can be solved forward as

$$\Delta p_t = \frac{\kappa}{1 - \beta\mu\rho} y_t + \epsilon_t, \tag{14}$$

assuming ϵ is i.i.d. As can be seen, both κ and μ affect the reduced-form Phillips-curve slope. In particular, a greater degree of nominal rigidity, and thus a smaller value of κ, would predict a reduced sensitivity of inflation to fluctuations in output. And so would a smaller degree of attention—that is, a smaller value of μ. Thus, estimating the Phillips curve with only information on inflation and the output gap would not allow us to distinguish between these two hypotheses. Of course, this is a very stylized model. But we will show later that in more realistic settings, a similar result holds: Shifts in either κ or μ lead to changes in the response of inflation to an aggregate demand shock. An implication is that if in fact the attentiveness of agents has fallen, then assuming $\mu = 1$, as is done in most estimation of New Keynesian models, will lead to a mistaken finding that κ has fallen. The purpose of the present paper is to bring additional information to bear, in the form of data on survey expectations, to help distinguish between these hypotheses.

3. Data and Estimation Details

3.1 Data

Central to our analysis are measures of inflation expectations. One measure is from the Survey of Consumer Attitudes and Behavior conducted monthly by the Survey Research Center at the University of Michigan. This measure of expectations has been collected on a consistent basis since 1978. It measures median household expectations of inflation over the coming 12 months. We also look at surveys of professional forecasters—in particular, the Survey of Professional Forecasters that is currently conducted by the Federal Reserve Bank of Philadelphia. The Survey of Professional Forecasters has several questions about inflation expectations, including forecasts of the

CPI, that are available for most of our sample. For consistency with the Michigan survey, we focus on median expectations over the coming year from these surveys. In the online appendices (available at http://www.ijcb.org), we consider additional measures of inflation expectations, including forecasts of GDP prices from the Survey of Professional Forecasters and the Livingston survey, an alternative survey of inflation forecasters.[12]

In most of our work, we use the CPI for items other than food and energy as the basis for our measure of inflation. We focus on a "core" measure, excluding food and energy, because the New Keynesian model is a model of sticky prices; food and energy prices are relatively volatile and thus the underlying model is not as appropriate for them (see Aoki 2001 for a discussion). We look at the CPI for two reasons. First, it is explicitly the variable that respondents to the SPF are asked to forecast. Second, it is the most widely cited measure of consumer prices and so is likely to line up with the views of respondents to the Michigan survey of households. For our measure of the output gap, we use the measure from the Congressional Budget Office (CBO).

In our empirical work, we detrend inflation and inflation expectations using an estimate of long-run inflation expectations. Specifically, we subtract from our measures of inflation and year-ahead inflation expectations a measure of longer-run inflation expectations that is available in the database for the Federal Reserve's FRB/US model.[13] Such detrending puts our focus on cyclical movements in inflation, which lines up with the emphasis of the theoretical models.

[12]The SPF only began asking about the CPI in 1981. We examined two techniques for extending the sample back to 1978. In one, we relied on the Kalman filter underlying our Bayesian estimation method to fill in the missing values. In the other, we projected the SPF's CPI forecasts on the survey's GDP deflator forecasts, which are available over a longer sample. Both approaches yielded similar results; we report the results from the former method.

[13]Data from the FRB/US model are available at https://www.federalreserve.gov/econres/us-models-about.htm. Specifically, we use the FRB/US variable PTR. Over most of its history, this measure of long-run expectations is based on forecasts of longer-run inflation from surveys of professional forecasters. An alternative approach to estimating trend inflation relies on statistical filters—see, for example, Stock and Watson (2007). We believe that a survey-based measure is more appropriate for our purposes. In particular, it allows us to rely on surveys for both short- and longer-term expectations, removing a possible source of discrepancy.

It also allows us to exploit the greater frequency of cyclical movements, which should allow us to better identify our key parameters. Because our focus is on short-term expectations, we do not address the question of greater "anchoring" of long-run inflation expectations that has recently received some attention.[14] The evolution of the central bank's inflation target, and its implications for the public's expectations for inflation over the longer run, is discussed, for example, in Erceg and Levin (2003).[15]

Here and throughout our empirical work, we will compare estimates over two periods, 1978 to 1996 and 1997 to 2015. The start of the sample is determined by the availability of quantitative measures of year-ahead inflation expectations in the Michigan survey of households. We then divide the sample roughly in half. Dräger and Lamla (2018) and Eusepi et al. (2019) have also noted that after 1996, inflation expectations became more anchored. As our results will demonstrate, the responsiveness of inflation to fluctuations in economic activity is very different in our two subsamples.[16]

3.2 Estimation Approach

While we do not make the benchmark assumption of model-consistent expectations throughout, model-consistent expectations nonetheless play a role in our model. Because our approach is uncommon, it is worthwhile explaining in a bit more detail.

In our model, agents' expectations $E_t \Delta p_{t+1}$ are determined by Equation (5). In particular, these expectations appear in the structural Phillips curve, Equation (8). As can be seen in Equation (5), model-consistent expectations $M_t \Delta p_{t+1}$ play a role in expectations formation, as discussed in Section 2. Crucially, where model-consistent expectations appear, they are solved using the full structure of the model, in the usual way. In particular, the solver for the model (specifically, Dynare) uses the full structure of the model in determining $M_t \Delta p_{t+1}$. This cross-equation aspect of our estimation approach enhances our ability to obtain precise

[14] See, for example, Dräger and Lamla (2018) and Eusepi et al. (2019).

[15] Our empirical equations also include constant terms, which could pick up, for example, biases in trend inflation or the output gap.

[16] In Section 5.2 we explore an alternative split between two subsamples.

estimates of both the Phillips-curve slope κ and the parameters of the expectations process, μ and λ.

We estimate our model using Bayesian methods, implemented using Dynare. The priors for our Bayesian estimation are laid out in the online appendices and are relatively uninformative and the same for both our subsamples. For each estimation, we use two blocks of 500,000 Markov chain Monte Carlo (MCMC) draws using the Metropolis–Hastings algorithm; in total, 1 million draws. In tables, we report the mean posterior estimates together with 90 percent confidence intervals. All estimations include constants in both the Phillips curve and the inflation expectations equation to account for potential differences in the measure of inflation reported by survey respondents and the core CPI inflation.[17]

4. System Estimation Results

In this section, we turn to estimates of the full system of equations outlined in Section 2.1. We compare estimates of the hybrid New Keynesian Phillips curve under two hypotheses about expectations: the model-consistent expectations assumption that is common in the literature and our model of expectations formation that relaxes MCE.

4.1 Model Estimates: MCE

Columns 1 and 2 of Table 1 present estimates of the system of equations consisting of the hybrid New Keynesian Phillips curve, Equation (8), and the reduced-form output gap equation, Equation (9), under the assumption of fully model-consistent expectations. Column 1 shows results over the 1978–96 period; column 2, over the 1997–2016 period. The slope of the Phillips curve, κ, is considerably smaller in the latter sample, by a factor of six-and-a-half. The degree of indexation, γ, is also notably smaller in the latter sample. Posterior mean estimates of γ and κ in the post-1996 sample are outside the 90 percent credible set of its estimate for the earlier sample.

The bottom rows of the table show results for the reduced-form process for the output gap, Equation (9). The parameters ϕ_1 and ϕ_2

[17]For brevity, we do not report the constants in the tables shown in the paper.

Table 1. Estimates of Model under Assumption of Model-Consistent Expectations and with Survey Inflation Expectations

	(1) MCE 1978–1996	**(2) MCE 1997–2015**	**(3) Michigan 1978–1996**	**(4) Michigan 1997–2015**	**(5) SPF CPI 1978–1996**	**(6) SPF CPI 1997–2015**
γ	0.739	0.320	0.139	0.566	0.432	0.211
	[0.534, 0.933]	[0.119, 0.522]	[–0.102, 0.375]	[0.133, 0.993]	[0.093, 0.761]	[–0.008, 0.422]
κ	0.072	0.011	0.271	0.143	0.331	0.077
	[0.015, 0.124]	[0.003, 0.018]	[0.111, 0.423]	[0.065, 0.222]	[0.155, 0.504]	[0.033, 0.120]
σ_ϵ	1.991	0.565	1.568	0.796	2.159	0.600
	[1.676, 2.282]	[0.478, 0.648]	[1.136, 1.986]	[0.528, 1.069]	[1.550, 2.741]	[0.467, 0.722]
λ	—	—	0.786	0.390	0.778	0.454
			[0.682, 0.898]	[–0.013, 0.802]	[0.683, 0.874]	[0.299, 0.621]
μ	—	—	0.198	–0.046	0.159	0.336
			[0.087, 0.303]	[–0.340, 0.244]	[0.087, 0.230]	[0.196, 0.472]
σ_ν	—	—	0.322	0.218	0.163	0.064
			[0.172, 0.458]	[0.075, 0.352]	[0.081, 0.241]	[0.021, 0.104]
ρ	—	—	0.879	0.640	0.837	0.256
			[0.743, 1.000]	[0.452, 0.847]	[0.496, 1.000]	[0.000, 0.470]
σ_ω	—	—	0.319	0.379	0.175	0.135
			[0.172, 0.458]	[0.285, 0.475]	[0.083, 0.261]	[0.099, 0.171]
$\varnothing_1$	1.219	1.292	1.214	1.315	1.229	1.331
	[1.039, 1.398]	[1.128, 1.461]	[1.039, 1.394]	[1.142, 1.490]	[1.050, 1.415]	[1.161, 1.502]
$\varnothing_2$	–0.273	–0.290	–0.260	–0.328	–0.277	–0.343
	[–0.455, –0.095]	[–0.459, –0.119]	[–0.441, –0.079]	[–0.510, –0.152]	[–0.454, –0.093]	[–0.517, –0.165]
$\varnothing_3$	–0.106	–0.115	–0.099	–0.035	–0.101	–0.082
	[–0.177, –0.037]	[–0.331, 0.097]	[–0.168, –0.026]	[–0.253, 0.179]	[–0.173, –0.031]	[–0.296, 0.138]
$\varnothing_4$	–0.055	–0.251	–0.046	–0.179	–0.040	–0.120
	[–0.132, 0.023]	[–0.465, –0.044]	[–0.125, 0.031]	[–0.393, 0.032]	[–0.119, 0.042]	[–0.335, 0.101]
σ_η	0.655	0.584	0.659	0.581	0.661	0.581
	[0.563, 0.743]	[0.503, 0.665]	[0.568, 0.746]	[0.500, 0.659]	[0.569, 0.752]	[0.500, 0.660]

Note: Estimated using Bayesian methods: see text for details; the priors are described in online appendix B. 90 percent confidence intervals are in square brackets.

suggest that the process in both periods has the "hump-shaped" pattern typical of the response of output to identified aggregate demand shocks in estimated structural VARs and DSGE models; there is a posterior mean estimate greater than one on the first lag of the gap and a negative estimate on the second lag. ϕ_3 and ϕ_4 show the sensitivity of the output gap to lagged inflation. In each estimation period, the sum of the two estimates is negative, as expected.

4.2 Model Estimates: Generalized Model of Expectations

Columns 3 to 6 of Table 1 present results for the model we introduced in Section 2.1, in which the assumption of model-consistent expectations is relaxed and survey expectations are added as an observable. Recall from Equations (5) and (6) that the model of expectations has several key features: It allows expectations to react to incoming information by less than predicted by the MCE hypothesis ($\mu < 1$); it allows for gradual adjustment of expectations ($\lambda > 0$); and it allows for shocks to the process for inflation expectations, either in the form of measurement error in the survey ($\sigma_\nu > 0$) or as shocks to correctly measured expectations, which can go on to affect actual inflation ($\sigma_\eta > 0$).

Results with the Michigan survey are in columns 3 and 4. Focusing first on the parameters related to inflation expectations, the results suggest a substantial departure from purely model-consistent expectations in both samples. In particular, the posterior mean estimates of μ are smaller than one in both samples, and by a large margin. The results in the early sample provide strong support for Carroll (2003)'s epidemiological model: The sum of the estimates μ and λ is 0.98, very close to the value of one suggested by Carroll's model. Thus, although households do not react immediately to new information about future inflation, under the epidemiological interpretation, the knowledge would eventually spread.

Estimates of both μ and λ are smaller in the later sample. In the early sample, the credible set for μ lies above zero, while in the latter sample, the point estimate is actually negative, albeit close to zero. Moreover, the estimates in the latter sample are outside the credible set for the early sample. A value of $\mu = 0$ would imply that households no longer pay attention to macroeconomic fundamentals in setting their inflation expectations.

Turning next to the estimates for the slope of the Phillips curve, κ, we find that, as with the MCE estimates, κ is smaller in the 1997–2015 sample. However, the extent of the decline in κ is considerably smaller than in the MCE case, with the estimate of κ dropping from 0.27 to 0.14, a decline of about 50 percent, compared with a decline of 85 percent in the first two columns. The mean posterior estimate of κ in the first sample lies outside the credible set for the second sample. According to the canonical Calvo model, this reduction in the value of κ corresponds to less-frequent price adjustment in the post-1996 sample.

On our preferred interpretation, a key reason for the smaller decline in the slope coefficient when the MCE assumption is relaxed is that households pay considerably less attention to the fundamentals in forming expectations than was the case in the earlier period, as indicated by the smaller value of μ. Thus, the smaller reduction in κ is consistent with the view that, at least in part, the reduction in the sensitivity of inflation to economic activity can be explained by a reduction in the attention paid to inflation by firms and households. As we will see in Section 6.1, the rise in inattention explains about three times more of the reduction in the overall sensitivity of inflation to economic activity than the reduction in κ.

In the early sample, there is little evidence of inflation persistence: $\gamma = 0.14$, where the credible set includes zero. This finding is consistent with the results of Roberts (1997) and Fuhrer (2017), who also found that conditioning on survey expectations led to reduced evidence of other sources of inflation persistence. γ rises to 0.57 in the latter sample.

Both measurement error and structural shocks to expectations are important sources of variation in the Michigan survey. The structural shock to expectations (σ_ν) is somewhat less important in the latter sample, with a standard deviation that is about two-thirds as large—although each estimate lies within the credible set of the other. In addition, λ is considerably smaller in the latter sample, so that any given shock will be carried forward with less persistence in the latter sample and, as we will see in Section 4.4, ν accounts for much less of the variability in inflation in the latter sample. Measurement error is large in both samples; it also displays considerable serial persistence, especially in the early sample.

As noted in Section 2, we interpret our structural expectations shocks as a form of sunspot. As discussed in Lubik and Schorfheide (2004), sunspots are more likely to arise when central bank control of inflation is weak. Our early sample includes the late 1970s and early 1980s, a period that a number of authors have identified as a period of transition from weak inflation control (Clarida, Galí, and Gertler 2000, Lubik and Schorfheide 2004, Roberts 2006). On this interpretation, it is not surprising that sunspot-related shocks are more prevalent in our early sample.

Columns 5 and 6 present results for the SPF.[18] Starting with the results for the expectations process, as with the Michigan survey, the simple MCE hypothesis is strongly rejected, with μ far from the MCE-implied value of one in both estimation periods. Also like the Michigan survey, the sum of λ and μ is fairly close to one in the early sample (= 0.94) and falls in the latter sample. One key difference from the Michigan results is the evolution of μ over time: For the SPF, the point estimate of μ actually rises somewhat in the latter period, in contrast to the sharp drop for the Michigan survey. That result suggests that professional forecasters continued to pay attention to fundamentals, albeit imperfectly, in the post-1996 sample, in contrast to the households captured by the Michigan survey, who, apparently, paid essentially no attention in the latter sample. We return to an interpretation of this finding in Section 4.3.[19]

[18]The SPF potentially exhibits a structural break in 1990:Q2, when the Federal Reserve Bank of Philadelphia started administrating the survey (before it was conducted by the American Statistical Association and the National Bureau of Economic Research). When we discuss robustness in Section 5.2, we perform the same analysis using alternative measures of expectations of professional forecasters.

[19]For the latter sample, our results on the attentiveness of professional forecasters are similar to those of Coibion and Gorodnichenko (2015a) and Mertens and Nason (2018). Those authors find that from about the mid-1990s onward, the professional forecasters captured by the SPF were relatively inattentive. Our results differ from these authors for the pre-1997 sample, however: Coibion and Gorodnichenko (2015a) and Mertens and Nason (2018) find that from the early 1970s through the early 1990s, SPF respondents were relatively attentive, with a weight on $M_t \Delta p_{t+1}$ that is close to one. There are many differences in statistical approach across these three papers. One is that we are imposing a structural New Keynesian Phillips curve as the model underlying the inflation process, which the other papers do not do. However, as we discuss in Section 5.1, we obtain similar results using a single-equation approach. We leave a resolution of these differences to future research.

For the Phillips curve, the early-sample estimates are broadly similar to those for the Michigan survey: The point estimate of κ is similar and, while the estimate for γ is larger with a credible set excluding zero, it is nonetheless of modest size. The results for the latter sample are different, however—the slope coefficient κ falls by about 75 percent, considerably more than for the Michigan survey—and are reminiscent of the MCE results presented in Section 4.1. The point estimates in each sample lie outside the credible set in the complementary sample.

As with the Michigan survey, there is evidence of both measurement error and structural shocks to expectations. The results suggest, however, that measurement error is less important for the SPF than for the Michigan survey, as both σ_ω and the persistence of measurement error, ρ, are smaller for the SPF, especially in the later sample. The structural expectations shock, ν, is also less important for the SPF than for the Michigan survey and, as with measurement error, is even less important in the latter sample.

For both the SPF and the Michigan survey, the point estimates of the Phillips-curve slope parameter are very different from those in columns 1 and 2—in particular, they are much larger than in the MCE case, in both samples. In their overview of empirical work on the New Keynesian Phillips curve, Mavroeidis, Plagborg-Møller, and Stock (2014) also find that estimates of κ are larger when expectations are proxied using surveys. The larger value of κ is consistent with the intuition provided by the simple model introduced in Section 2.2: When agents are less attentive, expectations of future inflation move less for any given change in the current-period output gap. To account for the same observed change in inflation, the model ascribes a larger role to the current-period output gap.

4.3 A Case for Preferring the Michigan-Based Results

Coibion, Gorodnichenko, and Kamdar (2018) argue strongly that the Michigan survey is to be preferred as a measure of inflation expectations. They argue that the preferred measure of inflation expectations is that of firms, as it is their expectations that most matter for pricing decisions. They cite their own work with inflation expectations in New Zealand, which suggests that expectations of firms are similar to those of households. As Carroll (2003) emphasizes, professional forecasters can be expected to be better informed than others about the state of the economy.[20] Thus, Michigan survey expectations may be closer to the expectations of decisionmakers in the economy than are the expectations of professional forecasters. Coibion, Gorodnichenko, and Kamdar (2018) go on to cite earlier work by two of them (Coibion and Gorodnichenko 2015b) that found that the Michigan survey was particularly helpful in explaining the lack of disinflation in the Great Recession. And they present new evidence suggesting that the Michigan survey performs better in empirical inflation models.

The results in Table 1 are broadly consistent with this view: consistent with the Greenspan hypothesis, the estimate of μ based on the Michigan survey is very small in the latter sample. In addition, the decline in κ is relatively modest in this case, with a decline of about 50 percent, consistent with the view that a larger decline in attentiveness implies a smaller decline in κ.

Cecchetti et al. (2017) argue that in recent decades, survey measures of inflation expectations have not been helpful in explaining actual inflation dynamics, in contrast to results in earlier (Roberts 1997) and longer (Mavroeidis, Plagborg-Møller, and Stock 2014; Fuhrer 2017) samples. Our results help explain why this might be the case. First, in our latter sample, μ is very small, notably so for the Michigan survey. Hence, the survey conveys less useful information about expectations of future economic conditions. Second, the structural (sunspot) shock to expectations is less important in the latter sample. So surveys are bringing less independent information to bear in the latter sample. As noted earlier, this outcome is consistent with predictions that in periods with greater inflation control by the central bank, sunspot equilibria are less likely to arise.

[20] Indeed, to the extent that professional forecasters make their living providing accurate assessments of the economy's evolution, it is perhaps not surprising that they would continue to pay appropriate attention to the relation between macroeconomic conditions and inflation. It is therefore possible that while these forecasts are more accurate, they are at the same time less relevant to price setting.

Table 2. Variance Decomposition for the Michigan Survey and Core CPI Inflation Based on Parameter Estimates in Table 1, Columns 3 and 4

	(1) Michigan 1978–1996	(2) Michigan 1997–2015	(3) Core CPI 1978–1996	(4) Core CPI 1997–2015
ε (Shock to the PC)	4	0	52	66
η (Aggregate Demand Shock)	37	0	32	27
ν (Structural Shock to Exp.)	39	19	15	7
ω (Measurement Error to Exp.)	21	81	0	0
Variance	2.2	.30	4.1	.47
Standard Deviation	1.5	.55	2.0	.68

Note: Table entries are the percent of variance of each variable explained by each of the model's shocks.

4.4 Variance Decompositions

In this section, we examine the contributions of the model's structural shocks to the variability of inflation and inflation expectations. Columns 1 and 2 of Table 2 present a formal variance decomposition of the Michigan survey in the two samples, based on the results in columns 3 and 4 of Table 1. In the early sample, the variation of the Michigan survey is importantly influenced by the business cycle: The cycle (η) accounts for 37 percent of the variability of the Michigan survey (column 1). The structural shock to expectations (ν) also accounts for a substantial portion of the variability of the Michigan survey, while the measurement error shock accounts for about one-fifth of the total variation.

In the latter sample, column 2, the coefficient μ is set equal to its theoretical lower bound of zero. As a consequence, neither of the economy's fundamental shocks, ϵ and η, account for any part of the Michigan survey's variation. Measurement error (ω) accounts for 80 percent of the variability of the Michigan survey in the latter sample. Thus, fluctuations in the Michigan survey are largely noise in the post-1996 period. It is worth noting, however, that the total

Table 3. Variance Decomposition for the SPF and Core CPI Inflation Based on Parameter Estimates in Table 1, Columns 5 and 6

	(1) SPF CPI 1978–1996	(2) SPF CPI 1997–2015	(3) Core CPI 1978–1996	(4) Core CPI 1997–2015
ε (Shock to the PC)	8	5	73	60
η (Aggregate Demand Shock)	56	65	24	38
ν (Structural Shock to Exp.)	28	10	3	2
ω (Measurement Error to Exp.)	9	20	0	0
Variance	.67	.10	4.7	.49
Standard Deviation	.82	.32	2.2	.70

Note: Table entries are the percent of variance of each variable explained by each of the model's shocks.

amount of noise in the Michigan survey is actually smaller in the latter sample. That's because the total variation in the Michigan survey is dramatically lower (the variance falls by around 85 percent).

Columns 3 and 4 of Table 2 show the contributions of the model's shocks to the variance of core CPI inflation in the two subsamples. The business cycle shock, η, accounts for around 30 percent of the variability of core CPI inflation in both samples. As with the results in columns 1 and 2, it is important to remember that the variance of inflation is much smaller in the latter sample, here falling by almost 90 percent. So in the latter sample, the business cycle is explaining 27 percent of a small number. In the early sample, the structural shock to inflation expectations accounts for about 15 percent of the variability of inflation. Thus, "sunspots" make a nontrivial contribution to the variability of inflation in this period. By assumption, survey measurement error makes no contribution to the variability of actual inflation.

Table 3 shows variance decompositions based on the model estimates for the SPF, from columns 5 and 6 of Table 1. As with the Michigan survey, the shock to the cycle—η—accounts for a substantial portion of the variability of inflation in both samples. One key difference in the results is that the fundamental shocks ϵ and, especially, η continue to account for a large portion of the variability of the SPF in the latter sample, as, according to the results in Table 1, SPF respondents continue to put important weight on the fundamentals in forming their inflation expectations.

5. Robustness

In this section, we provide various sensitivity analyses. We first look at single-equation methods. We then check the robustness of our multi-equation results with respect to different processes of inflation expectations, different measures of inflation expectations, different process and measure of the output gap, allowing for correlation of shocks in the estimation, regarding our detrending method, and to the definition of the two subsamples.

5.1 Single-Equation Estimates

In this section, we present single-equation, instrumental-variable estimates of our central equations of interest, the New Keynesian Phillips curve, Equation (8), and our model of expectations formation, Equation (5). These single-equation estimates provide a check on the robustness on the multi-equation approach of Section 4, in particular relaxing the assumptions that underlie our structural model.

We derive our equations for single-equation estimation by reorganizing our structural model in Section 2 as orthogonality conditions in which only observable variables appear. We then look for instruments that will be correlated with the observables and uncorrelated with the equation residuals. We begin by combining Equations (5) and (6) to obtain the following orthogonality condition related to survey expectations:

$$\nu_t + u_t - \lambda u_{t-1} + \mu(M_t \Delta p_{t+1} - \Delta p_{t+1}) = S_t \Delta p_{t+1} - \lambda S_{t-1} \Delta p_t - \mu \Delta p_{t+1}. \quad (15)$$

We seek instruments that are correlated with the terms on the right-hand side of Equation (15) and orthogonal to terms on the left-hand side. The first left-hand-side term, ν, will be correlated with any variable directly affected by the contemporaneous structural shock to expectations; importantly, ν is itself not serially correlated. In this case, both contemporaneous inflation and the survey itself are excluded as instruments. Note that, from Equation (13), the next two terms, u_t and u_{t-1}, which capture survey measurement error, are serially correlated. Thus, because any lagged values of the observable survey expectation $S_t\Delta p_{t+1}$ that appears in Equation (15) are excluded. Finally, the term $\mu(M_t\Delta p_{t+1} - \Delta p_{t+1})$ reflects the forecast error of inflation in period $t+1$ for forecasts made in period t. Because this forecast error is by assumption a rational one, it should not be serially correlated. The presence of this term would exclude any future variable as an instrument.

We can combine Equations (8) and (6) to obtain the following orthogonality condition related to the Phillips curve:

$$\epsilon_t - \beta u_t = (1+\beta\gamma)\Delta p_t - \gamma\Delta p_{t-1} - \beta S_t\Delta p_{t+1} - \kappa y_t. \qquad (16)$$

Any variable not directly affected by contemporaneous inflation will be uncorrelated with the first term, ϵ. Thus, contemporaneous inflation itself and contemporaneous survey expectations would be excluded; lagged values of inflation are acceptable. Given our structural model, the contemporaneous output gap would be an acceptable instrument. In this analysis, however, we relax this assumption and only allow lagged values of the output gap to serve as instruments. As with the estimation of Equation (15), the presence of u_t excludes current or lagged values of the survey $S_t\Delta p_{t+1}$ appearing in Equation (16) as instruments.

We include the following variables as instruments in the estimation of Equations (15) and (16): In both equations, we include two lags of the output gap and of the inflation gap as instruments. As noted above, because measurement error is serially correlated in our model, lagged values of the survey that is included in each equation are not valid instruments. Note, however, that the survey universes of the two main surveys we examine—the Michigan survey of households and the Survey of Professional Forecasters—are entirely independent of one another. Thus, the measurement errors of these two surveys are not correlated. In Equation (15), we use two lagged values of the (complementary) survey; in the Phillips curve, we use the contemporaneous and one lagged value.

An important consideration in the estimation of models using instrumental variables is the explanatory power of the instruments for the observables. In a recent survey article, Andrews, Stock, and Sun (2019) recommend the use of the "effective F" statistic proposed by Montiel-Olea and Pflueger (2013) as the preferred robust test for instrument power. Unfortunately, the effective F statistic has only been worked out in the case of one instrumented variable in an equation and each of our equations includes two such variables. As an alternative, we report results from another robust weak-instrument test, the Kleibergen-Paap test, which is suitable for the case of multiple endogenous variables. For comparison, we also report the robust F statistic from the first-stage regression for each variable.[21]

A final consideration is that, because instruments can be weak not only when their correlation with the endogenous variable is literally zero but also when it is in a neighborhood around zero, conventional F distributions are not used. Instead, more conservative thresholds have been proposed: Montiel-Olea and Pflueger (2013) advocate a threshold of 23, while in their recent survey Andrews, Stock, and Sun (2019), drawing on earlier work by Staiger and Stock (1997), suggest that 11 may be conservative enough.[22]

Table 4 shows our estimates of Equations (15) and (16).[23] Many of the results in Table 4 are similar to those from our system estimation. For the equation explaining the surveys (columns 1, 2, 5, and 6), the coefficient on expected inflation drops notably across samples in the equation for the Michigan survey, but not in the equation explaining the SPF, just as in our structural results. For the Phillips curve (columns 3, 4, 7, and 8), the coefficient on the output gap is roughly similar in both samples when expectations are captured by the Michigan survey, but the coefficient falls dramatically in the latter sample when expectations are captured by the SPF—again, as in our structural estimation. And as before, the coefficient on the

[21] As a cross-check, we also computed the effective F statistic for each endogenous variable; the results were qualitatively similar to those from the reported robust F statistics.

[22] These thresholds compare with a conventional-F 5 percent rejection threshold of around 2 in the case of moderate overidentification.

[23] For estimation, we use GMM with an HAC weighting matrix that assumes a Bartlett kernel and a Newey-West serial-correlation adjustment computed with a fixed bandwidth of 4.

Table 4. Single-Equation Estimates with GMM

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Michigan Survey				SPF Survey			
Dep. Var.→	$S_t\Delta p_{t+1}$		$\Delta p_t - \beta S_t \Delta p_{t+1}$		$S_t\Delta p_{t+1}$		$\Delta p_t - \beta S_t \Delta p_{t+1}$	
Sample→	**1978–1996**	**1997–2015**	**1978–1996**	**1997–2015**	**1978–1996**	**1997–2015**	**1978–1996**	**1997–2015**
$S_{t-1}\Delta p_t$	.689	.417	—	—	.744	.757	—	—
	(.082)	(.300)			(.094)	(.247)		
	[43.4]	[4.6]			[48.8]	[50.9]		
Δp_{t+1}	.246	.053	—	—	.121	.150	—	—
	(.094)	(.119)			(.042)	(.180)		
	[9.9]	[5.9]			[14.6]	[6.6]		
$\Delta p_{t-1} - \beta \Delta p_t$	—	—	.287	–.036	—	—	.071	–.015
			(.141)	(.130)			(.172)	(.108)
			[6.2]	[23.5]			[9.4]	[26.2]
y_t	—	—	.122	.155	—	—	.186	.025
			(.083)	(.030)			(.109)	(.030)
			[83.2]	[335.0]			[117.6]	[340.7]
$P(j\text{-}stat)$	.22	.27	.72	.39	.73	.22	.51	.58
F statistics	5.6	20.5	27.7	31.8	2.9	3.0	16.1	66.8

Note: In columns 1–2 and 5–6, two lags of the inflation gap, two lags of the output gap, two lags of the other survey (SPF for Michigan, Michigan for SPF) are used as instruments. In columns 4–5 and 7–8, two lags of inflation gap, two lags of output gap, current value, and one lag of other survey (SPF for Michigan, Michigan for SPF) are used as instruments. Coefficient standard errors are in parentheses. Brackets include first-stage robust F statistics for instruments for that variable. The F statistic for the overall estimation is the Kleibergen-Paap F statistic.

term related to lagged inflation is economically small and, in three of four cases, not significantly different from zero.

While broadly consistent with the results from the system estimation, these results come with a number of caveats. First, and as might be expected, the parameter estimates are less precise than in our system approach, which benefits from imposing restrictions implied by theory. Second, weak-instrument tests often fail. This is especially true for the survey equation, where for three of four specifications, the Kleibergen-Paap statistic is below even the more generous Staiger-Stock criterion of 11. The instruments are stronger in the case of the Phillips curve, where in three of four cases the Kleibergen-Paap statistic is beyond the strict Montiel-Olea and Pflueger (2013) threshold of 23. One bright spot is that the over-identifying restrictions, captured by the J-statistic, are not rejected in any of the eight cases.

5.2 Sensitivity of Full-System Estimates

We examine the robustness of our multi-equation estimates along a number of dimensions.[24] We begin by assessing the sensitivity of the inflation expectations process. We relax Equation (5) by allowing a more general process of expectation formation that allows the key features of a reduced-form Phillips-curve relationship—the output gap and lagged inflation—to enter the specification for inflation expectations directly (see Equation (A.1) in online appendix A). Table A.1 presents the results. As in Carroll (2003) and Pfajfar and Santoro (2013), the credible set of the estimate on the past inflation rate includes zero for the Michigan survey. For the early-sample SPF estimates of the same coefficient, the credible set also includes zero, while for the later period it does not.

The credible set on the estimate for the output gap excludes zero in three of the four cases. From the standpoint of our structural model of expectations formation, these results suggest that inflation expectations are more sensitive to economic activity than would be justified by the model structure. Of course, Equation (A.1) can itself be viewed as a Phillips-curve relationship. This is the approach taken by Dräger, Lamla, and Pfajfar (2016), who examine the individual

[24]The results in this section are available in the online appendices to this paper.

responses underlying the surveys and find that only about a third of participants in the Michigan survey forecast unemployment and inflation consistent with the Phillips curve trade-off, while the share for the SPF is about one-half.[25]

For the SPF, the estimates of the key parameters of the Phillips curve, γ and κ, are similar to those in Table 1. For the Michigan survey, however, the estimate of κ is substantially smaller, and credible sets in both samples include zero. As we discuss in the online appendices, this may be because the output gap has a very strong direct effect on expectations in this model.

We also check whether oil-price shocks play an important role in forming inflation expectations. Coibion and Gorodnichenko (2015a), for example, show the importance of oil prices for formation of inflation expectations. We thus further augment Equation (A.1) by including oil-price shocks calculated as in Hamilton (1996). Our results indicate that oil-price shocks are insignificant in all regressions and do not directly influence the formation of inflation expectations in either of our samples. Results are presented in Table A.4.[26]

Third, we check the robustness of our estimates with respect to the measure of inflation expectations. In Table A.2, we present the results for the Livingston survey and the SPF forecast of the GDP price deflator. Results are discussed in detail in the online appendices. In general, they confirm our baseline results.[27]

In our fourth exercise, we take the position that three of the measures of expectations of consumer prices—from the SPF, the Livingston survey, and the Michigan survey—are noisy indicators of the same underlying process. Thus, we assume that the same "true"

[25]Similarly, Carvalho and Nechio (2014) find that only some households—in particular, those with at least a college degree—have interest rate expectations that are broadly consistent with the Taylor rule.

[26]Our results differ from those of Coibion and Gorodnichenko (2015a), who find an important role of oil prices in determining inflation expectations. Our approach differs from theirs in a number of dimensions, most notably that we focus on oil-price shocks and on core CPI rather than oil prices directly and headline CPI.

[27]We also check the robustness of our results for the Michigan survey by considering only forecasts of those who have a college degree or high-income households. Binder (2015) points out that forecasts of these individuals are actually closer to the forecasts of firms. Results are presented in Table A.5 and are indeed very similar to our baseline results using the Michigan survey.

measure of expectations is a common factor driving all three surveys. Table A.3 shows results for this joint estimation. The results are similar to those for the SPF shown in Table 1, with the point estimate of κ falling substantially and μ rising across sample periods.

Fifth, we consider a more general process for the output gap. Specifically, to Equation (9), we add additional two lags of inflation and the output gap to check whether the process for output gap would importantly alter our results. As shown in Table A.6, the main results are virtually identical. The additional lags are sometimes important for the early sample, while for the latter sample they are always close to zero.

Sixth, we replace the CBO output gap in Equation (9) with the CBO short-run unemployment rate gap.[28] Results in Table A.7 again suggest that our results are unaffected by this change and the estimates of the slope of the Phillips curve are similar to the one that we would get if we were to multiply the estimates in Table 1 with an Okun's law coefficient of –0.5.

Seventh, we check the robustness of our estimates in the baseline Table 1 by allowing for various shocks in our system estimation to be correlated. Table A.8 shows the results when we allow $corr(\sigma_\eta, \sigma_\epsilon)$—that is, the correlation between Phillips-curve shocks and the output disturbances—to be nonzero. The estimates suggest that this correlation is small, with its credible set always including zero, and thus our main results are unchanged. In Table A.9, we additionally estimate $corr(\sigma_\nu, \sigma_\epsilon)$ (the correlation between the Phillips-curve shock and the shock to inflation expectations). For the Michigan survey, the results are again virtually unchanged, as this additional correlation is also small. In the early sample SPF $corr(\sigma_\eta, \sigma_\epsilon)$ is positive, while in the latter sample $corr(\sigma_\nu, \sigma_\epsilon)$ is negative. Nevertheless, the estimates of μ and κ are similar to those in Table 1, although λ is lower in the late sample and γ is higher.

Eighth, we study sensitivity with respect to the detrending procedure, estimating the model without detrending. Estimates are available in Table A.10. Results are again very similar to the baseline results in Table 1.

[28]The CBO differentiates between long-run and short-run natural rate of unemployment, while the latter is designed to be used for forecasting inflation.

Ninth, we check the robustness of our results to a different definition of the break between the early and late sample. The choice of a break in 1997 is in line with one of the two breaks considered in Ball and Mazumder (2019). Dräger and Lamla (2018) and Eusepi et al. (2019) also show that after 1996 inflation expectations became more anchored. Alternatively, the literature that studies breaks in inflation process suggest that there may be a break somewhere between 1991 and 1993 (see, for example, Cecchetti and Debelle 2006). Thus, as a robustness test, we impose a break in the middle of 1992. Results are presented in Table A.11 and are very similar to those for our baseline subsamples.

In the last robustness check, we study the sensitivity of our late-sample SPF CPI results to a measure of one-year-ahead inflation expectations (ATSIX) derived from SPF CPI forecasts and Blue Chip forecasts that was proposed by Aruoba (2020) and is updated by the Federal Reserve Bank of Philadelphia. This measure has the advantage that it allows for a computation of inflation expectation at time t for forecast between t and $t + 4$.[29] The results using the ATSIX measure are reported in Table A.12, where for a comparison we reproduce our results from column 6 of Table 1. The results are very similar to the baseline.

6. Structural Interpretation

6.1 Implications for Inflation Dynamics

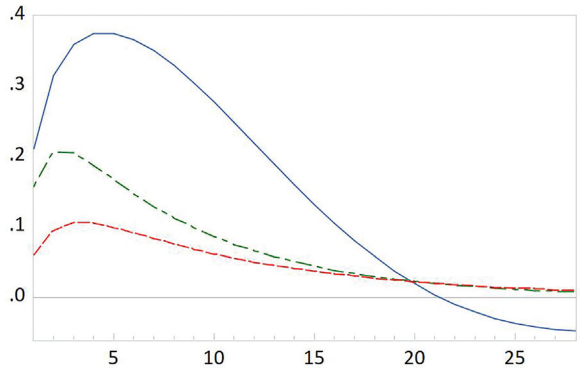
In this section, we use impulse responses to evaluate our two hypotheses and to explore the ability of changes in expectations formation to account for these changes in inflation dynamics.

Figure 1 shows the effects of a one-standard-deviation shock to the output gap equation in different variants of the model that uses the Michigan survey as its measure of inflation expectations. The solid blue line shows the results from the estimates in column 3 of Table 1, which used data from the 1978–96 period data.[30] In

[29] Strictly speaking, due to timing of the SPF, the inflation forecast that we use in our baseline analysis is at time $t-0.5$ for forecast between t and $t + 4$, which means that the information set in this forecast is less consistent with the model compared to the ATSIX one-year-ahead inflation expectations.

[30] For figures in color, see the online version of the paper at http://www.ijcb.org.

Figure 1. Impulse Response Function of Inflation to an Aggregate Demand Shock in the Structural Model



Note: Solid blue line presents results from model in column 3, Table 1, using the 1978–96 period and the Michigan survey. Red dashed line presents results that substitute the inflation and inflation expectations results from column 4 of Table 1, using the 1997–2015 period and the Michigan survey. In the green dot-dashed line, only the inflation expectations equation estimates from column 4 are used. See text for further details.

the dashed red line, the estimates for the equations for inflation and inflation expectations use the results from column 4 of Table 1, which are based on the 1997–2015 sample. To isolate the effects of the change in inflation dynamics, the dashed red version uses the same output gap equation as in the solid blue simulation. Consistent with the notion that aggregate demand shocks have a smaller impact on inflation than in the past, the effects of the aggregate demand shock are much larger in the earlier sample; for example, the peak effect is more than three times greater and the average effect over the first 12 quarters is similarly greater.

To isolate the contribution of the change in inflation dynamics, the dot-dashed green line shows a simulation that uses the estimated expectations-formation equation from the latter period along with the inflation equation from the early period. According to this simulation, the change in the inflation expectations process explains about 75 percent of the reduced effect of the aggregate demand shock on inflation over the first 12 quarters. Shifts in the structural Phillips-curve parameters, κ and γ, account for the rest.

6.2 Micro Evidence on the Frequency of Price Change

As mentioned in the introduction, Nakamura et al. (2018) find that prices changed more often in the United States in the high-inflation period of the late 1970s and early 1980s than in the subsequent period. In this section, we assess the potential implications of such a reduction in the frequency of price change for estimates of the slope of the Phillips curve.

As discussed in, for example, Woodford (2003), the slope of the Phillips curve in the New Keynesian model can be thought of as composed of two components, one related to the frequency of price change (α) and the other to the sensitivity of marginal cost to the state of the economy (ζ):

$$\kappa = \frac{(1-\alpha)(1-\beta\alpha)}{\alpha}\zeta, \tag{17}$$

where, recalling Equation (11), κ is the slope of the New Keynesian Phillips curve:

$$\Delta p_t = \beta E_t \Delta p_{t+1} + (1-\beta)\bar{\pi} + \kappa y_t + \epsilon_t. \tag{18}$$

According to the Ball, Mankiw, and Romer (1988) hypothesis, we would expect the frequency of price change α to be lower in recent years than in the high-inflation period, as there is less need to change prices in a low-inflation environment. This prediction lines up with the findings of Nakamura et al. (2018): They find that about 15 percent of prices changed each month in the 1978–81 period, compared with about 10 percent per month, on average, in the 1983–2014 period. Inserting these values into Equation (17) would imply that a reduction in the frequency of price change from 15 percent per month to 10 percent per month would lead to a reduction of about 50 percent in the Phillips-curve parameter κ, assuming other parameters are unchanged.

The 50 percent reduction in κ should probably be viewed as an upper bound for comparison with our estimates, however. Our empirical work compares the period 1978 to 1996 with 1997 to 2015. That suggests that our early sample mixes periods of relatively frequent and infrequent price changes. If we take an average of Nakamura et al. (2018)'s results over the 1978 to 1996 period, that suggests that, on average, the frequency of price change was about 11 percent per month, which would imply a reduction in the slope of the Phillips curve of only about 15 percent when comparing our early and late samples.

In our estimation of the conventional hybrid New Keynesian Phillips curve in the first two columns of Table 1, the drop in the estimate of κ was considerably larger than the 15–50 percent range suggested by the results of Nakamura et al. (2018). Thus, it appears that while the microeconomic evidence on the frequency of price change suggest some reduction in the Phillips-curve slope, it cannot fully account for the reduction in κ under the assumption of model-consistent expectations. By contrast, the drop in κ when we assume that expectations are well captured by the Michigan survey, as in columns 3 and 4 of Table 1, is just below 50 percent, within the range predicted by Nakamura et al. (2018).

7. Policy Implications

We begin by pointing out some key policy implications of a flatter Phillips curve regardless of its source and then focus on implications that are unique to reduced attentiveness. A first observation concerns economic performance at the effective lower bound on nominal interest rates (ELB). Because of the ELB, central banks are limited in their ability to reduce interest rates during an economic downturn. As Kiley and Roberts (2017), among others, have noted, the ELB can cause a significant deterioration in economic performance, and is a greater concern in the low-interest-rate environment that has prevailed in recent decades. However, when the Phillips curve is flatter, the adverse effects of the ELB are reduced. That's because inflation will fall by less in an economic downturn, and if nominal interest rates are bounded by the ELB, a smaller drop in inflation will mean that real interest rates will be lower than otherwise, providing greater support to economic activity. So, in a low-interest-rate environment, a reduced sensitivity of inflation can be a blessing.

Another important implication of a flatter Phillips curve concerns the effects of forward guidance about interest rates. As Carlstrom, Fuerst, and Paustian (2015), among others, have emphasized, aggressive forms of forward guidance, in which the central bank promises to cut interest rates in the far-distant future, can have perverse effects in standard New Keynesian models; these counterintuitive implications have been called the "forward-guidance puzzle." Other things equal, a flatter Phillips curve will tend to make the forward-guidance puzzle less severe because the puzzling implications of forward guidance turn crucially on the reaction of inflation.

Carlstrom, Fuerst, and Paustian (2015) have noted that in models that weaken the assumption of strictly model-consistent expectations, the forward-guidance puzzle is less problematic. They cite in particular the sticky information model of Mankiw and Reis (2002), which they show attenuates considerably the more puzzling aspects of forward guidance. Our empirical work finds strong support for alternatives to the standard MCE model, for all measures of expectations and in all periods. Our alternative is similar in many respects to the sticky information model of Mankiw and Reis (2002) that Carlstrom, Fuerst, and Paustian (2015) consider; in earlier work, Chung, Herbst, and Kiley (2015) had also found that alternatives to MCE—in this case, the Mankiw-Reis model that Carlstrom, Fuerst, and Paustian (2015) consider—also outperformed MCE empirically. Thus, the most extreme forms of the puzzle are unlikely to be features of real-world economies. In the limit, if expectations formation is as inattentive as our estimates with the Michigan survey in our post-1996 sample suggest, the forward-guidance puzzle does not arise at all.[31]

8. Conclusion

We examine the role that changes in the attentiveness of households and professional forecasters may have played in the reduction in the sensitivity of inflation to aggregate demand in the past couple of decades. Our most dramatic results are from the Michigan survey of households, where it appears that households now pay very little attention to macroeconomic conditions in setting their inflation expectations. In contrast, there is little evidence of a reduction in attentiveness among the respondents to the Survey of Professional Forecasters. It is perhaps not surprising that professional forecasters

[31] Relatedly, Beqiraj, Bartolomeo, and Pietro (2019) show that when inflation expectations are formed adaptively, the forward-guidance puzzle does not arise.

would continue to stay appropriately attuned to economic conditions in their forecasts; after all, that is their bread and butter. But as argued by Coibion and Gorodnichenko (2015b), it is plausible that the expectations of the firms that actually set prices are closer to those of households than of professional forecasters. Simulation results suggest that the reduced attentiveness in our Michigan survey results can account for the bulk of the decline in the overall sensitivity of inflation to aggregate demand shocks in the past couple of decades—around three-fourths. The remaining shift—which is ascribed in the New Keynesian model to a reduction in the frequency of price change—is in the range predicted by the microeconomic evidence on shifts in the frequency of price adjustment documented by Nakamura et al. (2018).

It may be that the reduction in the frequency of price change and the reduction of attention paid by price setters are not entirely distinct phenomena. The Volcker disinflation set off a number of important changes in U.S. monetary policy. First and foremost, average inflation has been lower. Ball, Mankiw, and Romer (1988) predicted that lower inflation would lead to a step-down in the frequency of price setting, and the results of Nakamura et al. (2018) confirm that such a change may have occurred. In addition, low inflation has historically tended to be more stable. In the U.S. case, one reason may have been that after the Volcker disinflation, monetary policy became more focused on inflation control; see, for example, Clarida, Galí, and Gertler (2000). The greater stability of inflation may have led firms and households to dedicate less bandwidth to monitoring inflation, as predicted by Greenspan. In addition, greater inflation control may have contributed to a reduction in sunspot-type fluctuations, as discussed by Lubik and Schorfheide (2004).

References

Adam, K., and Padula, M. 2011. "Inflation Dynamics and Subjective Expectations in the United States." *Economic Inquiry* 49 (1): 13–25.

Andrews, I., J. Stock, and L. Sun. 2019. "Weak Instruments in Instrumental Variables Regression: Theory and Practice." *Annual Review of Economics* 11: 727–53.

Aoki, K. 2001. "Optimal Monetary Policy Responses to Relative-Price Changes." *Journal of Monetary Economics* 48 (1): 55–80.

Aruoba, S. B. 2020. "Term Structures of Inflation Expectations and Real Interest Rates." *Journal of Business and Economic Statistics* 38 (3): 542–53.

Atkeson, A., and L. E. Ohanian. 2001. "Are Phillips Curves Useful for Forecasting Inflation?" *Quarterly Review* (Federal Reserve Bank of Minneapolis) (Winter): 2–11.

Ball, L., N. G. Mankiw, and D. Romer. 1988. "The New Keynesian Economics and the Output-Inflation Trade-off." *Brookings Papers on Economic Activity* 19 (1): 1–82.

Ball, L., and S. Mazumder. 2011. "Inflation Dynamics and the Great Recession." *Brookings Papers on Economic Activity* 42 (1) (Spring): 337–405.

———. 2019. "A Phillips Curve with Anchored Expectations and Short-Term Unemployment." *Journal of Money, Credit and Banking* 51 (1): 111–37.

Beqiraj, E., G. D. Bartolomeo, and M. D. Pietro. 2019. "Beliefs Formation and the Puzzle of Forward Guidance Power." *Journal of Macroeconomics* 60 (June): 20–32.

Bils, M., and P. Klenow. 2004. "Some Evidence on the Importance of Sticky Prices." *Journal of Political Economy* 112 (5): 947–85.

Binder, C. C. 2015. "Whose Expectations Augment the Phillips Curve?" *Economics Letters* 136 (November): 35–38.

———. 2017. "Measuring Uncertainty Based on Rounding: New Method and Application to Inflation Expectations." *Journal of Monetary Economics* 90 (October): 1–12.

Blanchard, O. J. 2016. "The US Phillips Curve: Back to the 60s?" Policy Brief No. 16-1, Peterson Institute for International Economics.

Calvo, G. 1983. "Staggered Prices in a Utility-Maximizing Framework." *Journal of Monetary Economics* 12 (3): 383–98.

Carlstrom, C. T., T. S. Fuerst, and M. Paustian. 2015. "Inflation and Output in New Keynesian Models with a Transient Interest Rate Peg." *Journal of Monetary Economics* 76 (November): 230–43.

Carroll, C. D. 2003. "Macroeconomic Expectations of Households and Professional Forecasters." *Quarterly Journal of Economics* 118 (1): 269–98.

Carvalho, C., and F. Nechio. 2014. "Do People Understand Monetary Policy?" *Journal of Monetary Economics* 66 (September): 108–23.

Cecchetti, S. G., and G. Debelle. 2006. "Has the Inflation Process Changed?" *Economic Policy* 21 (46): 311–52.

Cecchetti, S. G., M. E. Feroli, P. Hooper, A. Kashyap, and K. L. Schoenholtz. 2017. "Deflating Inflation Expectations: The Implications of Inflation's Simple Dynamics." Working Paper, U.S. Monetary Policy Forum.

Christelis, D., D. Georgarakos, T. Jappelli, and M. van Rooij. 2016. "Trust in the Central Bank and Inflation Expectations." DNB Working Paper No. 537, Netherlands Central Bank.

Christiano, L., M. Eichenbaum, and C. L. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113 (1): 1–45.

Chung, H., E. Herbst, and M. T. Kiley. 2015. "Effective Monetary Policy Strategies in New Keynesian Models: A Reexamination." In *NBER Macroeconomics Annual 2014*, Vol. 29, ed. J. A. Parker and M. Woodford, 289–344 (chapter 5). Chicago: University of Chicago Press.

Clarida, R., J. Galí, and M. Gertler. 2000. "Monetary Policy Rules and Macroeconomic Stability: Evidence and Some Theory." *Quarterly Journal of Economics* 115 (1): 147–80.

Coibion, O., and Y. Gorodnichenko. 2015a. "Information Rigidity and the Expectations Formation Process: A Simple Framework and New Facts." *American Economic Review* 105 (8): 2644–78.

———. 2015b. "Is the Phillips Curve Alive and Well after All? Inflation Expectations and the Missing Disinflation." *American Economic Journal: Macroeconomics* 7 (1): 197–232.

Coibion, O., Y. Gorodnichenko, and R. Kamdar. 2018. "The Formation of Expectations, Inflation, and the Phillips Curve." *Journal of Economic Literature* 56 (4): 1447–91.

Coibion, O., Y. Gorodnichenko, S. Kumar, and M. Pedemonte. 2018. "Inflation Expectations as a Policy Tool?" NBER Working Paper No. 24788.

Dräger, L., and M. J. Lamla. 2012. "Updating Inflation Expectations: Evidence from Micro-data." *Economics Letters* 117 (3): 807–10.

———. 2018. "Is the Anchoring of Consumers' Inflation Expectations Shaped by Inflational Experience?" CESifo Working Paper No. 7042, CESifo Group Munich.

Dräger, L., M. J. Lamla, and D. Pfajfar. 2016. "Are Survey Expectations Theory-Consistent? The Role of Central Bank Communication and News." *European Economic Review* 85 (June): 84–111.

Erceg, C. J., and A. T. Levin. 2003. "Imperfect Credibility and Inflation Persistence." *Journal of Monetary Economics* 50 (4): 915–44.

Eusepi, S., E. Moench, B. Preston, and C. Viana de Carvalho. 2019. "Anchored Inflation Expectations." CEPR Discussion Paper No. 13900.

Fuhrer, J. 2017. "Expectations as a Source of Macroeconomic Persistence: Evidence from Survey Expectations in a Dynamic Macro Model." *Journal of Monetary Economics* 86 (April): 22–35.

Gabaix, X. 2017. "A Behavioral New Keynesian Model." Discussion Paper, Harvard University.

Gagnon, E. 2009. "Price Setting during Low and High Inflation: Evidence from Mexico." *Quarterly Journal of Economics* 124 (3): 1221–63.

Galí, J., and M. Gertler. 1999. "Inflation Dynamics: A Structural Econometric Analysis." *Journal of Monetary Economics* 44 (2): 195–222.

Greenspan, A. 2001. "Transparency in Monetary Policy." Speech, Federal Reserve Bank of St. Louis, Economic Policy Conference, St. Louis, Missouri, October 11.

Hamilton, J. D. 1996. "This is What Happened to the Oil Price-Macroeconomy Relationship." *Journal of Monetary Economics* 38 (2): 215–20.

Kiley, M. T., and J. M. Roberts. 2017. "Monetary Policy in a Low Interest Rate World." *Brookings Papers on Economic Activity* (Spring): 317–96.

Lamla, M. J., D. Pfajfar, and L. Rendell. 2019. "Inflation and Deflationary Biases in Inflation Expectations." BIS Working Paper No. 789.

Lubik, T. A., and F. Schorfheide. 2004. "Testing for Indeterminacy: An Application to U.S. Monetary Policy." *American Economic Review* 94 (1): 190–217.

Mankiw, N. G., and R. Reis. 2002. "Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve." *Quarterly Journal of Economics* 117 (4): 1295–1328.

Mavroeidis, S., M. Plagborg-Møller, and J. H. Stock. 2014. "Empirical Evidence on Inflation Expectations in the New Keynesian Phillips Curve." *Journal of Economic Literature* 52 (1): 124–88.

McKay, A., E. Nakamura, and J. Steinsson. 2016. "The Power of Forward Guidance Revisited." *American Economic Review* 106 (10): 3133–58.

———. 2017. "The Discounted Euler Equation: A Note." *Economica* 84 (336): 820–31.

Melosi, L. 2016. "Signaling Effects of Monetary Policy." Working Paper No. 2016-14, Federal Reserve Bank of Chicago.

Mertens, E., and J. M. Nason. 2018. "Inflation and Professional Forecast Dynamics: An Evaluation of Stickiness, Persistence, and Volatility." Working Paper No. 713, Bank for International Settlements.

Montiel-Olea, J. L., and C. Pflueger. 2013. "A Robust Test for Weak Instruments." *Journal of Business and Economic Statistics* 31 (3): 420–32.

Nakamura, E., and J. Steinsson. 2008. "Five Facts about Prices: A Reevaluation of Menu Cost Models." *Quarterly Journal of Economics* 123 (4): 1415–64.

Nakamura, E., J. Steinsson, P. Sun, and D. Villar. 2018. "The Elusive Costs of Inflation: Price Dispersion during the U.S. Great Inflation." *Quarterly Journal of Economics* 133 (4): 1833–1908.

Pfajfar, D., and E. Santoro. 2013. "News on Inflation and the Epidemiology of Inflation Expectations." *Journal of Money, Credit and Banking* 45 (6): 1045–67.

Pfajfar, D., and B. Zakelj. 2014. "Experimental Evidence on Inflation Expectation Formation." *Journal of Economic Dynamics and Control* 44 (July): 147–68.

Roberts, J. M. 1997. "Is Inflation Sticky?" *Journal of Monetary Economics* 39 (2): 173–96.

———. 2006. "Monetary Policy and Inflation Dynamics." *International Journal of Central Banking* 2 (3, September): 193–230.

Roth, M. 2013. "Inflation Expectations and the Stability of the Phillips Curve Relationship." Working Paper, Goethe University Frankfurt.

Sims, C. A. 2003. "Implications of Rational Inattention." *Journal of Monetary Economics* 50 (3): 665–90.

Staiger, D., and J. Stock. 1997. "Instrumental Variables Regression with Weak Instruments." *Econometrica* 65: 557–86.

Stock, J. H., and M. W. Watson. 2007. "Why Has U.S. Inflation Become Harder to Forecast?" *Journal of Money, Credit and Banking* 39 (s1): 3–33.

Woodford, M. 2003. *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton, NJ: Princeton University Press.

Exchange Rate Shocks and Inflation Co-movement in the Euro Area*

Danilo Leiva-Leon,[a] Jaime Martínez-Martín,[b] and Eva Ortega[a]
[a]Banco de España
[b]European Central Bank

This paper decomposes the time-varying effect of exogenous exchange rate shocks on euro-area countries' inflation into country-specific (*idiosyncratic*) and regionwide (*common*) components. To do so, we propose a flexible empirical framework based on dynamic factor models subject to drifting parameters and exogenous information. We show that exogenous shocks are behind an important share of nominal EUR/USD fluctuations over the recent years. Our main results indicate that headline inflation in euro-area countries has become significantly more affected by exchange rate shocks since the early 2010s. While in the case of headline inflation this increasing sensitivity is solely reliant on the *idiosyncratic* component, for energy inflation it is based on both *idiosyncratic* and *common* components. By contrast, exchange rate shocks do not seem to have a significant impact on the core component of headline inflation.

JEL Codes: C32, E31, F31, F41.

1. Introduction

Exchange rate fluctuations over a short period of time may be due to a variety of reasons, which can be broadly grouped into three

*We would like to thank our colleagues of the Expert Group on Exchange Rate Pass-Through of the European System of Central Banks as well as seminar participants at the Banco de España, the International Association for Applied Econometrics 2019 Annual Conference, and the SAEe 2019 for their stimulating and helpful comments. Also, we are thankful to Òscar Jordà and two anonymous referees for their helpful comments and suggestions. The views expressed in this paper are those of the authors and do not represent the view of the Banco de España, the European Central Bank, or the Eurosystem. Any errors are our own responsibility. Author e-mails: danilo.leiva@bde.es; jaime.martinez-martin@ecb.europa.eu; eortega@bde.es.

categories: (i) fresh developments relating to growth fundamentals of each economy, on either the demand or supply side; (ii) perceived changes in countries' respective monetary policies, since they have a bearing on the relative return of financial assets associated with each economy; and (iii) risk premium shocks not directly linked to economic or monetary fundamentals which can prompt strong and swift movements in exchange rate dynamics that are hard to identify and predict (these are usually referred to as exogenous exchange rate shocks).

From a policymaker's standpoint, assessing the effects that currency movements may have on price inflation is crucial for the design of a monetary policy framework. A clearer understanding of the transmission channels may improve not only the ability to predict the impact but also the ability to better understand the effects of central banks' actions in this context. As a result, a prolific literature has focused on analyzing the degree to which a country's import, producer, or consumer prices change in response to its exchange rate fluctuations. This is commonly known as exchange rate pass-through (hereafter, ERPT).[1] The literature on ERPT ranges from seminal theoretical studies (Dornbusch 1987; Krugman 1987; and Corsetti, Dedola, and Leduc 2008), which showed that ERPT to prices was incomplete due to imperfect competition and pricing-to-market, to cross-country empirical evidence (Campa and Goldberg 2005, 2010), which focused on slow-moving structural determinants, such as changes in the composition of imports. Recently, there have been more efforts to identify the factors behind the changes in ERPT over time from a micro data perspective on firm pricing (Gopinath, Itskhoki, and Rigobon 2010; Berger and Vavra 2013; Devereux, Tomlin, and Dong 2015; and Amiti, Itskhoki, and Konings 2016). These works highlight drivers such as the role of invoicing currency, whether the transactions take place between or within firms, the frequency and dispersion of price adjustments, and the role of competition in final product markets.

A recent line of empirical research has provided evidence that the size, the duration, and even the sign of the ERPT depend on the origin of the shocks behind exchange rate fluctuations. For

[1] More specifically, it is usually defined as the percentage change in prices in response to a 1 percent change in the exchange rate.

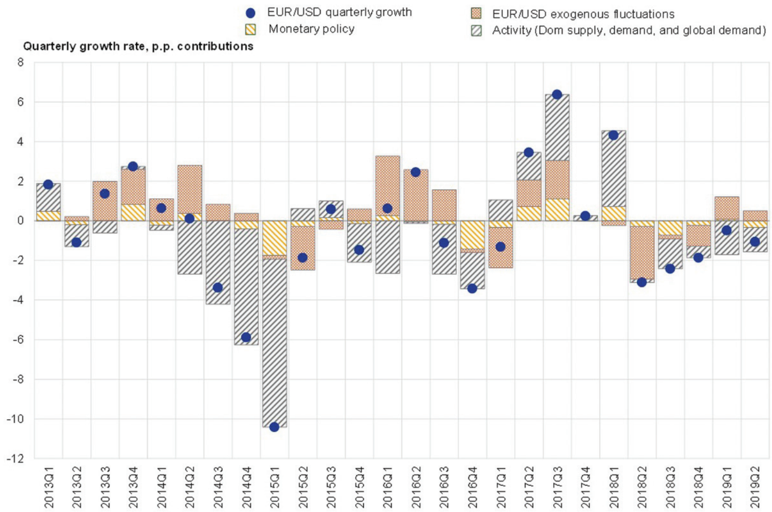
instance, Forbes, Hjortsoe, and Nenova (2015, 2018), following the work of Shambaugh (2008), estimate a structural vector autoregression (SVAR) framework for the United Kingdom as a small open economy. The authors highlight that it is essential to distinguish the driving forces behind the exchange rate fluctuations (i.e., whether they are due to domestic demand, global demand, domestic monetary policy, global supply shocks, domestic productivity, etc.) in order to explain how the ERPT has evolved. They also find that domestic monetary policy shocks are those with a relatively higher ERPT. A similar result was found for the euro area by Comunale and Kunovac (2017), using the same methodology. Their estimates point to a large but volatile ERPT to import prices and a very small EPRT to consumer inflation, lower than in previous decades.[2]

Theoretical models suggest a number of ways in which the exchange rate–prices nexus is shock dependent. These channels are corroborated by the related empirical literature. Yet, if the impact on prices varies in the euro area due to the changing composition of shocks driving the exchange rate movements, are they related to country-specific and/or euro-area-wide forces? The above-mentioned literature is silent on the cross-country heterogeneity inherent to a set of economies sharing their currency and monetary policy. Our proposed framework overcomes this drawback by jointly estimating the effect of euro-area (regionwide) exchange rate shocks on the inflation rates associated with the different economies (country specific).

This paper builds on the literature on shock-dependent exchange rate pass-through and elaborates further on the time variation and cross-country differences in the response of different price components to exchange rate changes in the euro area. Of all the sources of exchange rate fluctuations, this paper focuses only on exogenous exchange rate shocks (i.e., risk premium shocks not directly linked

[2]Using reduced-form approaches (not shock dependent), a body of empirical literature has put forward ERPT estimates for the euro area, showing evidence that the ERPT to consumer prices is about a tenth of that to import prices. Structural DSGE (dynamic stochastic general equilibrium) models, which consider the different transmission of different structural shocks, tend to deliver a higher and more gradual pass-through to consumer prices. For further details, see Ortega and Osbat (2020) and references therein such as Hahn (2003), Jašová, Moessner, and Takáts (2016), and Özyurt (2016).

Figure 1. Historical Decomposition of Nominal Exchange Rate USD/EUR



Note: Estimates based on the quarterly SVAR model of the USD/EUR exchange rate described in Section 2, where shocks are identified via sign restrictions. Estimates for 2019:Q2 are based on data available at the time of the cut-off date (September 2019). Data for U.S. and euro-area GDP in 2019:Q2 are based on flash estimates. The USD exchange rate movements refer to the quarterly rates of changes of the respective quarters. The figure depicts the average contribution of the 10,000 historical decompositions obtained from the saved iterations of the estimation algorithm.

to economic or monetary fundamentals) for at least two reasons. First, we seek to imitate insofar as possible the concept of ERPT in a shock-dependent context: we isolate the transmission to prices of “pure” exchange rate shocks from the joint reaction of prices and exchange rates to other structural shocks such as demand, supply, or monetary policy shocks. Second, we focus on exogenous exchange rate shocks for an empirical reason. As shown in our empirical results (see Figure 1), structural shocks other than exogenous exchange rate shocks account for an important share of the change in the nominal EUR/USD exchange rate—for around 65 percent since 1995—to be precise. However, exogenous exchange rate shocks have played a bigger part in unanticipated nominal exchange rate movements, not only in recent years but also during turning-point periods.[3] Our findings indicate that they are behind more than 50 percent of nominal EUR/USD exchange rate fluctuations in more than a third of the quarters of the past six years.

The contribution of this paper is twofold. First, we investigate potential changes over time in the effect that exogenous exchange rate shocks have on headline inflation in euro-area countries and on its corresponding components. For ease of exposition, we can express this goal in simple terms with the following equation:

$$INF_{i,t} = \phi_i(L)INF_{i,t-1} + \beta_{i,t}\epsilon_t^{ER} + v_{i,t}, \tag{1}$$

where $INF_{i,t}$ is the inflation rate of country i at time t, the term $\phi_i(L)$ helps control for past inflation dynamics, the exchange rate shocks are measured by ϵ_t^{ER}, and $v_{i,t}$ represents an error term.[4] Note that in Equation (1), our object of interest is the dynamics of $\beta_{i,t}$, which measures the changing sensitivity of inflation to exchange rate shocks.

Second, we decompose the sensitivity of inflation to exchange rate shocks across euro-area economies into two parts: one is exclusively related to the inflation dynamics of country i and the other is common to all euro-area countries. In other words, the latter can be interpreted as the sensitivity of country i inflation to exchange rate shocks that is formed jointly with other countries of the region. The following equation illustrates this decomposition:

$$\beta_{i,t} = IDI_{i,t} \times COM_t, \tag{2}$$

where $IDI_{i,t}$ denotes the idiosyncratic, country-specific component and COM_t denotes the common, regionwide component. The information contained in Equation (2) can be useful for policymakers to understand the extent to which movements in inflation of a given country, brought about by exchange rate shocks, can be attributed to its exclusive and intrinsic economic performance or to the overall performance of all monetary union partners.

[3]Turning-point periods are defined as switching states of EUR/USD valuations (i.e., transitions from appreciation to depreciation and vice versa) based on the monthly nominal EUR/USD reference exchange rate provided by the European Central Bank (ECB).

[4]The lag operator is denoted by L.

To jointly assess both the time variation in the sensitivity of inflation to exogenous exchange rate shocks and its decomposition into country-specific and regionwide components, we adopt a unified multi-country perspective. In particular, we first identify such exchange rate shocks using a structural VAR model for the aggregate euro-area economy. To ensure that shocks have the expected effect on the macroeconomy, according to theoretical models or stylized facts, we base our identification scheme on sign restrictions, along the lines of Shambaugh (2008), Forbes (2015, 2018), and Comunale and Kunovac (2017). Next, we use the exchange rate shocks as exogenous information in a dynamic factor model with drifting coefficients for inflation in the euro-area economies.[5] This empirical framework allows us to make accurate comparisons of the results across the different economies. In particular, it provides a full spectrum of the effect of exogenous exchange rate shocks on inflation (i) across countries, (ii) by subcomponents, and (iii) over time.

The main results show that the sensitivity of headline inflation to exchange rate shocks has increased since the early 2010s. In other words, an unexpected appreciation of the euro versus the dollar leads to larger declines in inflation than before. Such an increase is systemic and broad based, since most euro-area countries have experienced it. When assessing the source of such recent increased sensitivity of headline inflation to exchange rate shocks, it is found that (i) the euro-area-wide component, which can be interpreted as the effect of exchange rate shocks on aggregate euro-area inflation, has remained relatively stable over time; by contrast (ii) the country-specific component has displayed a substantial increase since the early 2010s. This implies that the growing sensitivity of headline inflation to exchange rate shocks is heavily reliant on the increasing similarities between inflation rate dynamics associated with the euro-area countries.

[5] The euro-area monetary union comprises 19 EU member states: Belgium (BE), Germany (DE), Estonia (EE), Ireland (IE), Greece (GR), Spain (ES), France (FR), Italy (IT), Cyprus (CY), Latvia (LV), Lithuania (LT), Luxemburg (LU), Malta (MT), the Netherlands (NL), Austria (AT), Portugal (PT), Slovenia (SI), and Finland (FI). Results for Slovakia (SK) are not reported due to data limitations.

By subcomponents—that is, energy, food, and core prices—the results are heteregoneous. First, the sensitivity of the energy component to exogenous exchange rate shocks has also increased significantly in recent years. Contrary to the case of headline inflation, this result relies equally on the country-specific and common components. Second, food inflation estimated sensitivity is similar to that of headline inflation, albeit less statistically significant. Third, core inflation sensitivity estimates behave somewhat different: core inflation across countries does not seem to be meaningfully affected by exogenous exchange rate shocks, along the lines of the empirical literature findings (Ortega and Osbat 2020). Therefore, our results suggest that the increase in the ERPT has been induced by an increasing headline inflation co-movement, mainly driven by its energy component.[6]

The structure of the paper is as follows: Section 2 sets out the empirical approach; Section 3 discusses the main findings, with particular focus on the assessment of inflation co-movement across countries; and Section 4 sets out the conclusions.

2. Empirical Framework

In this section, we provide an empirical framework to investigate the effects of exchange rate shocks on inflation in euro-area countries across both geographic and time dimensions. Therefore, we are interested in a modeling approach able to meet four main criteria: (i) to properly identify exchange rate shocks for the euro-area economy as a whole, given the unified monetary system; (ii) to estimate how the effect of those exchange rate shocks spreads across the different euro-area countries; (iii) to provide information on the potential changes over time in the sensitivity of each country to those shocks; and (iv) to decompose the changing sensitivity into its country-specific and regionwide components.

We proceed in two steps. First, we use a structural VAR model to identify purely exogenous exchange rate shocks. Second, according to the exogenous exchange rate shocks identified in the first step,

[6] At the same time, this component is highly influenced by shocks to global factors, such as oil prices.

we investigate their time-varying effect on inflation across euro-area countries using factor models.[7]

2.1 Structural VAR Model

We employ a structural vector autoregression model to investigate the exchange rate sensitivity of euro-area inflation, considering how different theory-based shocks may affect the exchange rate and prices. More specifically, we are interested in assessing the effects of five shocks on the euro-area economy: domestic supply, domestic demand, global demand, relative monetary policy, and exogenous exchange rate shocks. This is a similar variety of shocks as previously considered in related literature and should encompass all shocks that could be relevant drivers of exchange rate fluctuations. For instance, a sudden increase in domestic risk aversion would be captured as an exogenous exchange rate shock. To the extent that such unanticipated shocks may drive movements in the EUR/USD exchange rate, they may also determine the magnitude and duration of pass-through.

However, a major concern in this context is to link economic theory to identify the shocks of interest with appropriate restrictions on variables' impulse responses. The identification strategies historically used by the related literature in estimating ERPT—conditional on underlying shocks—have a number of limitations and are only able to identify a restricted set of shocks. More specifically, the seminal work of Shambaugh (2008) uses long-run restrictions to identify separately domestic supply, relative demand, nominal shocks, and foreign price shocks. The interpretation of the latter three types of shocks, however, is not straightforward and does not easily translate into standard macroeconomic models, and the identification strategy does not allow for disentangling shocks originating in different regions.

To address the identification challenge, we impose several short-run sign restrictions which are motivated by open-economy DSGE

[7]Similar methodological approaches have been used for exogenous changes in oil prices (Kilian 2009) or for potential output distinguishing between demand and supply shocks (Coibion, Gorodnichenko, and Ulate 2017).

models. In particular, these restrictions are consistent with the two-country New Keynesian model described in de Walque et al. (2017, 2020), the Banque Nationale de Belgique model of the euro-area economy, which entails the standard open-economy main characteristics. This DSGE model integrates two closed-economy models—for the euro area and the United States—through international trade in goods and assets, and it is rather rich in terms of features: sticky local-currency pricing, distribution sector, intermediate goods in the production function, and a demand elasticity increasing with the relative price. The shock transmission mechanisms of this standard open-economy model are described in more detail in the online appendices for this paper (available at http://www.ijcb.org).

Accordingly, to identify the main shocks driving the dynamics of the euro exchange rate against the U.S. dollar, we estimate an endogenous multivariate model that uses quarterly information about the euro-area real GDP growth rate (GDP), euro-area HICP inflation (INF), relative short-term interest rates (INT) between the euro area and the United States, the EUR/USD nominal exchange rate (FX), and the relative euro-area activity share with respect to the United States (EA/US). Therefore, let the vector collecting of the variables be $\mathbf{Y}_t = [GDP_t, INF_t, INT_t, FX_t, EA/US_t]$; the estimated model is a SVAR(p) model given by

$$\mathbf{Y}_t = \Phi_0 + \sum_{p=1}^{P} \Phi_p \mathbf{Y}_{t-p} + \mathbf{B}\epsilon_t, \tag{3}$$

where $\epsilon_t \sim N(0, I)$ are the structural innovations. The reduced-form innovations, defined as $\mathbf{u}_t$, are related to the structural innovations through the impact multiplier matrix $\mathbf{B}$, that is, $\mathbf{u}_t = \mathbf{B}\epsilon_t$.[8]

To identify the structural shocks of interest following the macroeconomic relations explained above, we impose sign restrictions on some of the entries of the impact multiplier matrix.[9] These sign

[8]In our empirical application, we let the number of lags of the endogenous variables be $p = 2$. Robustness tests on different lags are reported in the online appendices.

[9]A similar approach is used in Leiva-Leon (2017) for the case of Spain and Estrada et al. (2020) for emerging market economies.

restrictions have been widely used in the literature, have been shown to be consistent with theoretical models (see online appendices for further reference), and are based on four sets of assumptions.

First, we assume that a positive domestic supply shock, $\epsilon_t^{Dom\_Sup}$, is associated with an increase in domestic output and the relative euro-area activity share and a decrease in inflation, interest rates, and foreign exchange rates.[10] By contrast, a positive domestic demand shock, $\epsilon_t^{Dom\_Dem}$, would be associated with higher output and relative euro-area activity, higher HICP inflation, higher interest rates, and euro appreciation. Second, we assume that an unexpected tightening of the monetary policy stance, $\epsilon_t^{Mon\_Pol}$, that increases the short-term interest rate is associated with lower inflation, output growth, and relative share of euro-area activity with respect to the United States. Third, we impose that an unexpected euro appreciation, $\epsilon_t^{Exo\_ER}$, which increases the EUR/USD exchange rate, would lead to declines in inflation and the interest rate.[11] Fourth, we assume that a positive global demand shock, $\epsilon_t^{Glo\_Dem}$, that reduces the relative size of the euro-area economy compared with the world economy (proxied by the United States) exerts upward pressure on euro-area output and inflation, but would lead to a relatively looser monetary policy in the euro area than in the United States, where demand expansion would be larger after the positive global demand shock.[12] All these restrictions can be formalized as follows:

$$\begin{bmatrix} u_t^{GDP} \\ u_t^{INF} \\ u_t^{INT} \\ u_t^{FX} \\ u_t^{EA/US} \end{bmatrix} = \begin{bmatrix} + & + & - & * & + \\ - & + & - & - & + \\ - & + & + & - & - \\ - & + & * & + & * \\ + & + & - & * & - \end{bmatrix} \begin{bmatrix} \epsilon_t^{Dom\_Sup} \\ \epsilon_t^{Dom\_Dem} \\ \epsilon_t^{Mon\_Pol} \\ \epsilon_t^{Exo\_ER} \\ \epsilon_t^{Glo\_Dem} \end{bmatrix}, \tag{4}$$

[10] A decrease in the FX rate is defined as a reduction in the EUR/USD exchange rate, i.e., euro depreciation.

[11] For the sake of robustness, an alternative identification scheme concerning an unexpected appreciation of the nominal euro exchange rate (exogenous exchange rate shock or risk premium shock) is further developed in the online appendices. It provides broadly similar results.

[12] An important related aspect is the link between oil prices and exchange rate developments. In the online appendices, we further discuss this issue and provide model-based evidence of little impact on the key results by means of an SVAR-X approach.

where the "$*$" in the impact multiplier matrix indicates that the entries have been left unrestricted. This combination of sign restrictions is the minimum number of theory-based economically sensible restrictions that allows us to identify the shocks of interest and at the same time to ensure their orthogonality.[13]

We estimate the SVAR model, described in Equations (3)–(4), using quarterly data for the euro area and the United States for the period from 1995:Q1 to 2019:Q2 on the following six variables: (i) the euro-area real gross domestic product (GDP) growth rate from the European Commission (Eurostat); (ii) inflation based on the Harmonised Index of Consumer Prices (HICP) for the euro area from the European Commission (Eurostat); (iii) relative short-term interest rates between the euro area and the United States, and for the zero lower bound period, shadow rates based on quarterly averages of monthly estimates from Krippner (2013);[14] (iv) quarterly average of the monthly nominal EUR/USD reference exchange rate provided by the European Central Bank (ECB);[15] and (v) relative euro-area activity calculated as the ratio of euro-area to U.S. GDP, based on GDP data provided by the European Commission (Eurostat) and the U.S. Bureau of Economic Analysis (BEA). All variables except the relative interest rate are transformed into quarterly log differences.

Finally, the SVAR model is estimated using Bayesian methods. In particular, an independent normal-inverse-Wishart prior is assumed to simulate the posterior distribution of the parameters. Structural shocks are identified by following Arias, Rubio-Ramirez, and Waggoner (2018), where sign restrictions are imposed on impulse

[13]A wide range of estimation methodolgy robustness checks is discussed in the online appendices. The estimates obtained are qualitatively similar to those obtained with our benchmark specification in Equations (3)–(4).

[14]Model results are, in any case, robust to different monetary policy measures, such as relative official interest rates in the euro area and the United States and shadow interest rates. Shadow rates are constructed using multifactor shadow rate term structure models by Wu and Xia (2016).

[15]Our SVAR model results are robust to an alternative estimation using the nominal effective exchange rate of the euro against its main 38 trade partners—NEER-38 countries—although some caveats arise, as the variables proxying global demand and relative monetary policy are measured only in relation to the United States, not to the full set of 38 countries used in the NEER definition.

response functions. Further details of the estimation procedure are provided in the online appendices.

2.2 Factor Model with Exogenous Information

Dynamic factor models have been widely used to characterize the degree of co-movement in the dynamics of prices from different levels of disaggregation. Two examples are Del Negro and Otrok (2007), who focus on house prices at the state level for the U.S. economy, and Cicarelli and Mojon (2010), who present a global perspective of synchronized inflation dynamics across industrialized countries. Here, we use this tool to provide a comprehensive assessment of exchange rate effects on inflation in the euro-area countries from a unified perspective.

We use the exogenous exchange rate shocks extracted from the structural VAR model described above to assess their effect on inflation in the n euro-area countries. As suggested by Mumtaz and Sunder-Plassmann (2013), the effects associated with exchange rate fluctuations in advanced economies are subject to substantial changes over time. Hence, as we are primarily interested in assessing changes in the exchange rate sensitivity of inflation over time, we rely on a multivariate framework subject to time-varying coefficients.[16]

Taking the standardized inflation rate of country i defined as $\pi_{i,t} = (INF_{i,t} - \mu_{i,inf})/\sigma_{i,inf}$, where $\mu_{i,inf} = mean(INF_{i,t})$ and $\sigma_{i,inf} = std(INF_{i,t})$, we propose the following time-varying parameter factor model with exogenous information, referred to as TVP-DFX,

$$\pi_{i,t} = \gamma_{i,t} f_t + u_{i,t}, \tag{5}$$

$$f_t = \phi_t f_{t-1} + \lambda_t \epsilon_t^{Exo\_ER} + \omega_t, \tag{6}$$

for $i = 1, 2, \ldots, n$, and where $u_{i,t} \sim N(0, \sigma_i^2)$ and $\omega_t \sim N(0, 1)$. Note that Equation (5) decomposes country-specific inflation, $\pi_{i,t}$, into a common component, f_t, and an idiosyncratic component,

[16] A similar factor model with time-varying coefficients is also used in Ductor and Leiva-Leon (2016) to unveil an increasing synchronization in global real activity.

$u_{i,t}$, whereas Equation (6) assumes that the common factor follows autoregressive dynamics and that it is also influenced by exogenous information—in particular, by the exogenous exchange rate shocks $\epsilon_t^{Exo\_ER}$.

The model parameters are assumed to evolve according to random walks to account for potential instabilities over time,

$$\gamma_{i,t} = \gamma_{i,t-1} + \vartheta_{i,t} \tag{7}$$

$$\phi_t = \phi_{t-1} + \vartheta_{\phi,t} \tag{8}$$

$$\lambda_t = \lambda_{t-1} + \vartheta_{\lambda,t}, \tag{9}$$

where $\vartheta_{i,t} \sim N(0, \nu_i^2)$, $\vartheta_{\lambda,t} \sim N(0, \nu_\lambda^2)$, and $\vartheta_{\phi,t} \sim N(0, \nu_\phi^2)$. Most importantly, the time-varying degree of inflation co-movement across countries is captured by $\gamma_{i,t}$, while changes in the persistence of the latent factor are collected in ϕ_t, and the dynamic sensitivity of the inflation factor is measured by λ_t.

Plugging Equation (6) into Equation (5) gives us the following expression for country i inflation dynamics:

$$INF_{i,t} = \tilde{\beta}_{i,0} + \tilde{\beta}_{i,1,t} f_{t-1} + \tilde{\beta}_{i,2,t} \epsilon_t^{Exo\_ER} + \tilde{v}_{i,t}, \tag{10}$$

where $\tilde{\beta}_{i,0} = \mu_{i,inf}^i$, $\tilde{\beta}_{i,1,t} = \sigma_{i,inf}\gamma_{i,t}\phi_t$, $\tilde{\beta}_{i,2,t} = \sigma_{i,inf}\gamma_{i,t}\lambda_t$, and $\tilde{v}_{i,t} = \sigma_{i,inf}(\gamma_{i,t}\omega_t + u_{i,t})$. Note that there is a direct correspondence between Equation (10) and Equation (1)—in particular, between the coefficients measuring the sensitivity of inflation to exchange rate shocks in both equations, i.e., $\tilde{\beta}_{2,i,t}$ and $\beta_{i,t}$, respectively.

The main advantage of the proposed TVP-DFX model is that it allows the effect of exchange rate shocks on inflation, $\tilde{\beta}_{2,t}^i$, to be decomposed into two components: the country-specific component, $\gamma_{i,t}$, and the euro-area-wide component, λ_t, which would correspond to the terms $IDI_{i,t}$ and COM_t, respectively, in Equation (2). The term λ_t provides information about the changing effect that exchange rate shocks have on euro-area inflation dynamics, proxied by the factor f_t. By contrast, the term $\gamma_{i,t}$ provides information on the changing propagation of those shocks across the different countries of the euro area. Equation (10) is first estimated on headline HICP inflation across the euro-area economies. Section 3.2 discusses the findings, as well as the estimation of Equation (10) on the three components of HICP inflation (food, energy, and the core component, i.e., total HICP excluding food and energy prices). Note that an additional advantage of the proposed framework is that it can be used to incorporate structural shocks obtained from any other kind of model for validation purposes, i.e., semi-structural or DSGE models. However, in the current application we only focus on the shocks from the structural VAR model described in Section 2.1.

3. Sensitivity of Prices to Exchange Rate Shocks

3.1 An Aggregate Assessment

This section aims to help understand the link between movements in the EUR/USD and euro-area consumer prices. We analyze what types of shocks have driven the euro exchange rate fluctuations over the period 1995:Q1–2019:Q2 by examining historical shock decompositions from the SVAR detailed in Section 2.[17] To begin with, Figure 1 presents the historical decomposition of shocks behind the evolution of quarter-on-quarter EUR/USD exchange rate. It permits a better understanding of the relative weight of different shocks and its variation over time. An increase (reduction) is defined as an increase (reduction) in the EUR/USD in exchange rate, i.e., euro appreciation (depreciation) against the USD. Focusing on the most recent period, the contributions of the potential driving factors identified in the SVAR are the following: (i) innovations to real activity (either from domestic demand and supply or from the rest-of-the-world demand); (ii) relative monetary policy shocks; and (iii) exogenous exchange rate shocks not directly linked to fundamentals or monetary policy. As discussed earlier, exogenous factors may proxy risk premium shocks, which most notably reflect changes in the confidence, sentiment, or perception (optimism or pessimism) among traders operating on foreign exchange markets. They are usually sudden, strong, and difficult to predict.

A quick glance at Figure 1 suggests that structural shocks other than exogenous exchange rate shocks account for a large share of the EUR/USD fluctuations—for around 65 percent over the sample

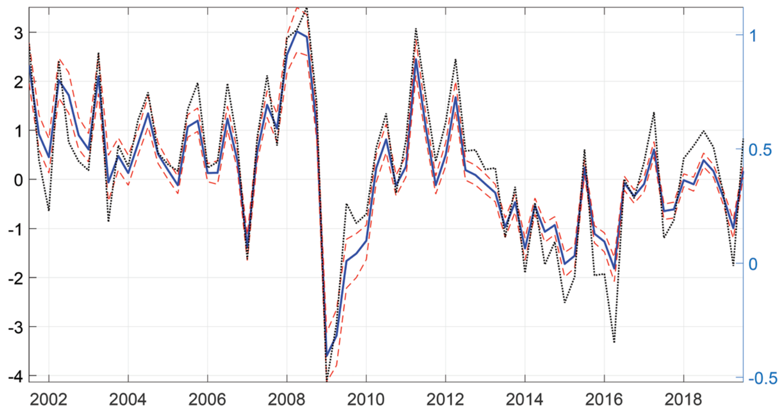
[17]Estimates for 2019:Q2 are based on data available at the time of the cut-off date (September 2019).

period, to be precise. Therefore, treating all exchange rate changes as exogenous shocks is unlikely to adequately capture the underlying dynamics—in particular, if the mix of shocks driving the exchange rate varies over time, as discussed in Section 1. However, exogenous exchange rate shocks have played a bigger part in unanticipated nominal exchange rate movements, not only in recent years but also in turning-point periods, that is, transitions either from appreciation to depreciation or from depreciation to appreciation. Our findings indicate that they are behind more than 50 percent of the exchange rate fluctuations in more than a third of the quarters of the past six years, as shown in Figure 1.

For example, according to our structural analysis, the euro's marked appreciation between 2017:Q2 and 2018:Q1 could have been driven by at least three forces. Ranked in order of importance, they are as follows: First, its appreciation may have been due to a higher relative growth of the euro area, which would have exerted an inflationary pressure. Second, it may have been due to exogenous factors exerting a deflationary effect (through a reduction in import prices). Third, it may have been because of the perception that the ECB's monetary policy was somewhat less relaxed at the end of 2017, relative to the Federal Reserve's, the latter also exerting a deflationary effect due to the relative monetary policy stance. These arguments are consistent with existing previous literature such as Cœuré (2017), which is an example of how shock-dependent estimates of the exchange rate–prices nexus are affecting the monetary policy debate. However, it has to be considered that these estimates may be very sensitive to the particular model specification (sample period, identification scheme, choice and measurement of variables), as argued in Ortega and Osbat (2020).[18]

[18] A full set of different model variants have also been estimated to test whether our findings are sensitive to alternative identification strategies, different lag orders and sign restriction periods, third-currency effects beyond the EUR/USD bilateral relationship (i.e., considering the nominal effective exchange rate of the euro), a version of our SVAR subject to time-varying parameters (TVP-SVAR), and the role of oil prices through the lenses of a SVAR-X model. The robustness results are summarized in the online appendices and show no remarkable differences neither in the historical decomposition of exchange rate shocks nor in specific, extracted shocks.

Figure 2. Euro-Area Headline Inflation Factor (f_t)



Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area headline quarterly inflation expressed in percentage points. (For figures in color, see the online version of the paper at http://www.ijcb.org.)

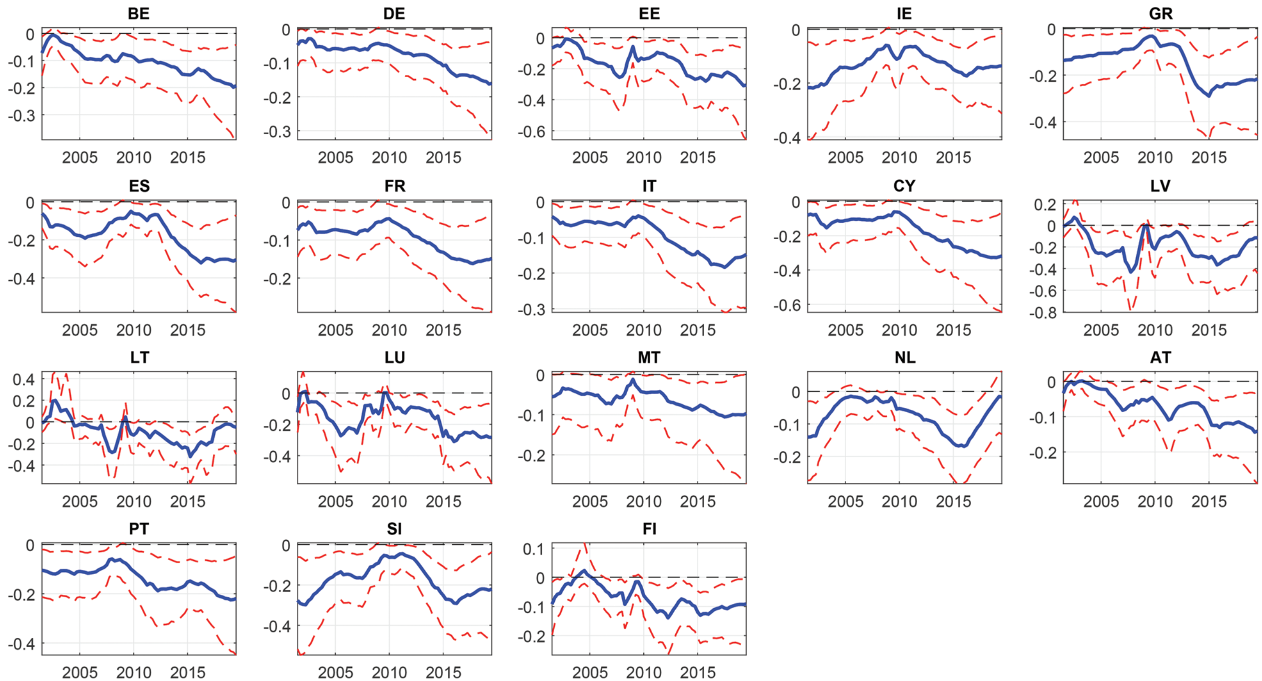
3.2 The Role of Inflation Co-movement

After estimating the proposed dynamic factor model with drifting coefficients and exogenous information, described in Equations (5)–(9), we proceed to assess the effect of exchange rate shocks on inflation (i) over time, (ii) across countries, and (iii) by price component.

We begin by focusing on the case of headline inflation. The common factor extracted from headline inflation across the euro-area countries is plotted in Figure 2. This is f_t in Equation (5), estimated using total HICP data for the euro-area countries. It shows a strikingly similar pattern to actual headline inflation for the euro area. Therefore, the estimated common factor f_t can be interpreted as a proxy for euro-area headline inflation dynamics.

Figure 3 plots the *total* estimated time-varying sensitivity of the euro-area countries' headline inflation to exchange rate shocks, that is, $\tilde{\beta}_{i,2,t}$ in Equation (10). The estimates suggest that a persistent increase in the effect of shocks on inflation occurred around 2010. This is a general pattern for most countries, but it is especially acute

Figure 3. Sensitivity of Country-Specific Headline Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\tilde{\beta}_{i,2,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the multivariate model.

for the largest economies. In particular, France, Germany, and Italy exhibited a sensitivity of around 0.1 before 2010, but which has since continued to increase, up to 0.2. For Spain the increase is even larger, up from 0.2 before 2010 to around 0.4 subsequently. Some smaller economies, such as Portugal, Finland, or Malta, have also experienced increasing sensitivity, but less persistently.[19] These results show traces that at the zero lower bound, and under credible forward guidance of the interest rates, the pass-through of the exchange rate changes to prices is larger.[20]

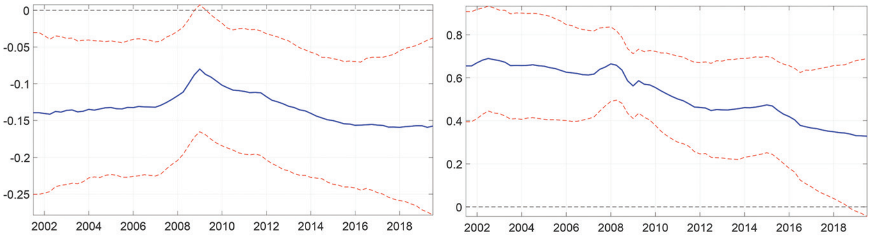
As the estimated common factor is a good proxy for euro-area headline inflation, the time-varying parameter λ_t in Equation (6) can be interpreted as the changing effect of exchange rate shocks on the aggregate euro-area inflation rate. Figure 4A plots the dynamics of the *regionwide* component of the *total* sensitivity, λ_t, showing that, in general, it has remained steady, the only exception being the Great Recession period when exogenous exchange rate shocks did not seem to have a significant effect on euro-area headline inflation. In particular, a 1 percent exogenous appreciation of the euro would be associated with a decline in euro-area HICP inflation of around 0.15 percent on impact.[21] By contrast, Figure 4B plots the

[19]To assess the importance of relying on the shocks rather than simply on the movements of exchange rate, we reestimate the proposed factor model, but replacing the exogenous exchange rate shocks, in Equation (6), with a simpler measure which consists on the quarterly change of the level of the exchange rate. The results indicate that when conditioning on the movements of the exchange rate, and not on its unexpected component, its time-varying pass-through to headline inflation across countries (i) is very small in magnitude, (ii) is estimated with large uncertainty, (iii) occasionally exhibits counterintuitive signs, and (iv) does not increase of decrease over time, but instead shows only temporary changes. These results are not shown for the sake of space, but they are available upon request.

[20]This result is consistent with the theoretical literature on the secular stagnation hypothesis and the idea that international trade relations become more conflictual at the zero lower bound (ZLB)—in particular, in those economies where a persistently low or negative natural rate of interest has led to a chronically binding ZLB and the central bank no longer dampens the effects of this kind of shocks. See Eggertsson, Mehrotra, and Summers (2016) and Eggertsson, Mehrotra, and Robbins (2019).

[21]The impact of monetary policy shocks on HICP inflation and its components has also been analyzed under the same empirical strategy, although it is beyond the scope of this paper. Empirical findings point to a decreasing path of sensitivity of inflation to these shocks.

Figure 4. Time-Varying Coefficients of Model for Headline Inflation



A. Sensitivity of Headline Inflation of the Euro Area (λ_t)   B. Persistence of the Euro-Area Headline Inflation Factor (ϕ_t)

Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

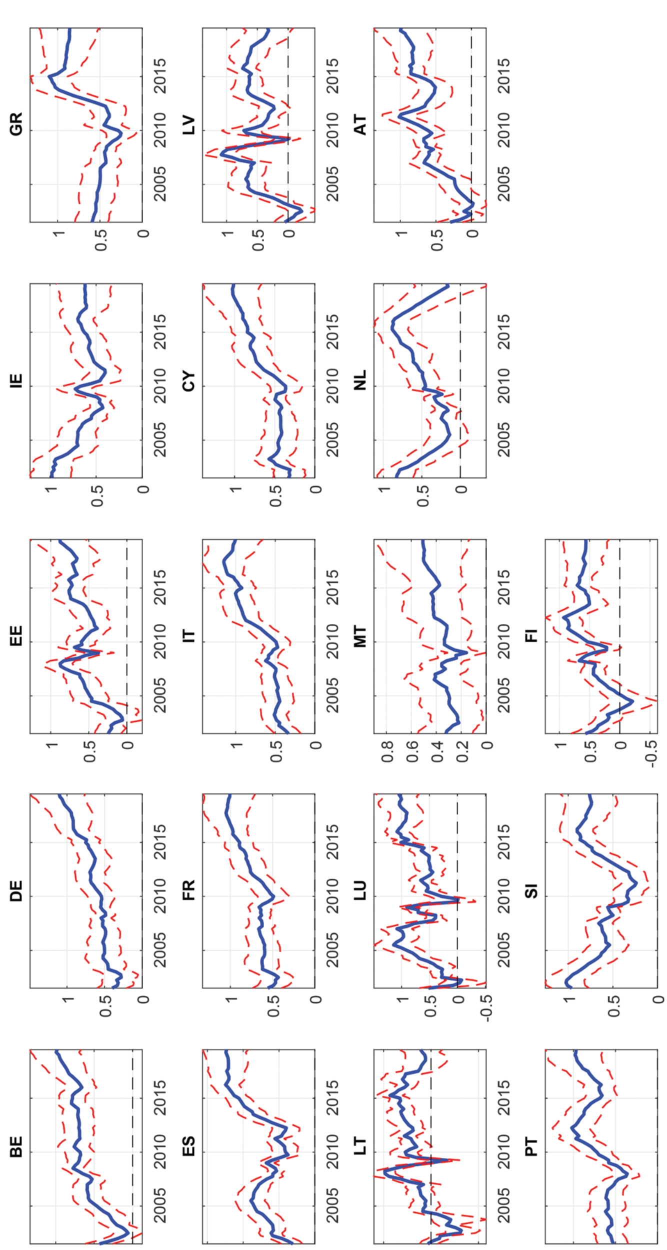
time-varying persistence of the common inflation factor, showing a slightly declining pattern since 2008.

Increasing sensitivity across countries, along with relatively stable sensitivity for the aggregate euro area, can be explained by an increasing degree of co-movement in headline inflation across euro-area countries. Figure 5 shows the estimated time-varying loadings of the common component into each country's inflation of Equation (5), that is, the *country-specific* component of the *total* sensitivity. Accordingly, the dynamics of $\gamma_{i,t}$ measure the changing contemporaneous relationship between country-specific inflation measures and their common factor. As expected, the figure reflects sustained increases over time in the synchronization of headline inflation dynamics for most countries.

In other words, the fact that inflation rates across euro-area countries have exhibited an increasing degree of co-movement over time implies that such countries are reacting in a more similar way to shocks hitting the euro area as a whole. Notice that the effect of exchange rate shocks on the common factor (which proxies the euro-area headline inflation) has just slightly increased since the Great Recession; see Figure 4A. However, this small increasing effect is amplified for the countries due to the fact that now they are more sensitive to these common shocks than in the past, as shown in the factor loadings dynamics reported in Figure 5.[22]

[22]The reasoning for these results relies on the evolving heterogeneity across inflation rates of euro-area countries. In particular, total inflation in some

Figure 5. Time-Varying Co-movement of Euro-Area Countries' Headline Inflation ($\gamma_{i,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Note that if country-specific forces start to strongly move in the same direction, eventually those forces would lose their idiosyncrasy and become a euro-area-wide force. However, the distinction between those two forces is not always straightforward to define in our context and, consequently, to measure. Our framework provides an attempt to perform this measurement from a reduced-form, and unified, perspective. Undoubtedly, a wide range of structural aspects come into play in explaining these differences; however, the analysis of these aspects goes beyond the scope of this paper. An illustrative example is the case of the Baltic economies (Estonia, Latvia, and Lithuania) during 2007 and 2010, when their inflation rates exhibited a temporary, but substantial, disengagement from the inflation rates of their union partners. This illustrates that while there were euro-area forces acting like an “attractor,” there were also strong country-specific forces induced by multiple structural changes, associated with high levels of trade openness and liberal economic policies taking place around that time (see Benkovskis et al. 2009).

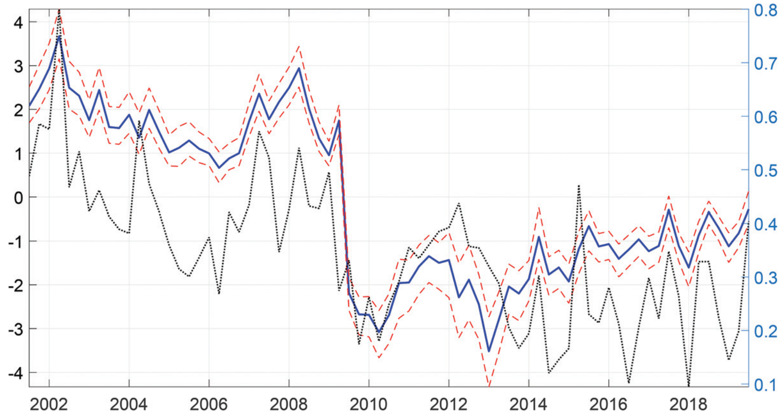
3.3 Breakdown by Inflation Subcomponents

In order to provide a comprehensive assessment of the exchange rate pass-through to inflation, it is also crucial to understand the impact that exchange rate shocks may have on the subcomponents of headline inflation. Therefore, the TVP-DFX framework is also used to independently model the subcomponents of headline inflation—core, food, and energy components—across euro-area countries.

We start by analyzing the core component. Figure 6 plots the common core inflation factor. Although the factor and euro-area core inflation follow a similar pattern, their similarity is not as marked as in the case of headline inflation. This points to a potentially lower degree of co-movement in the core component of inflation. Moreover, Figure 7 shows that the effect of exchange rate shocks on core inflation across countries is both negligible and very uncertain. This is

individual countries can become more sensitive to exchange rate shocks. However, that total inflation can be decomposed into two parts, a common and an idiosyncratic one, which are independent. Therefore, the common part of the inflation rate of those countries (which is based on all, and not only on some, countries) does not necessarily have to also become more sensitive to exchange rate shocks.

Figure 6. Euro-Area Core Inflation Factor (f_t)

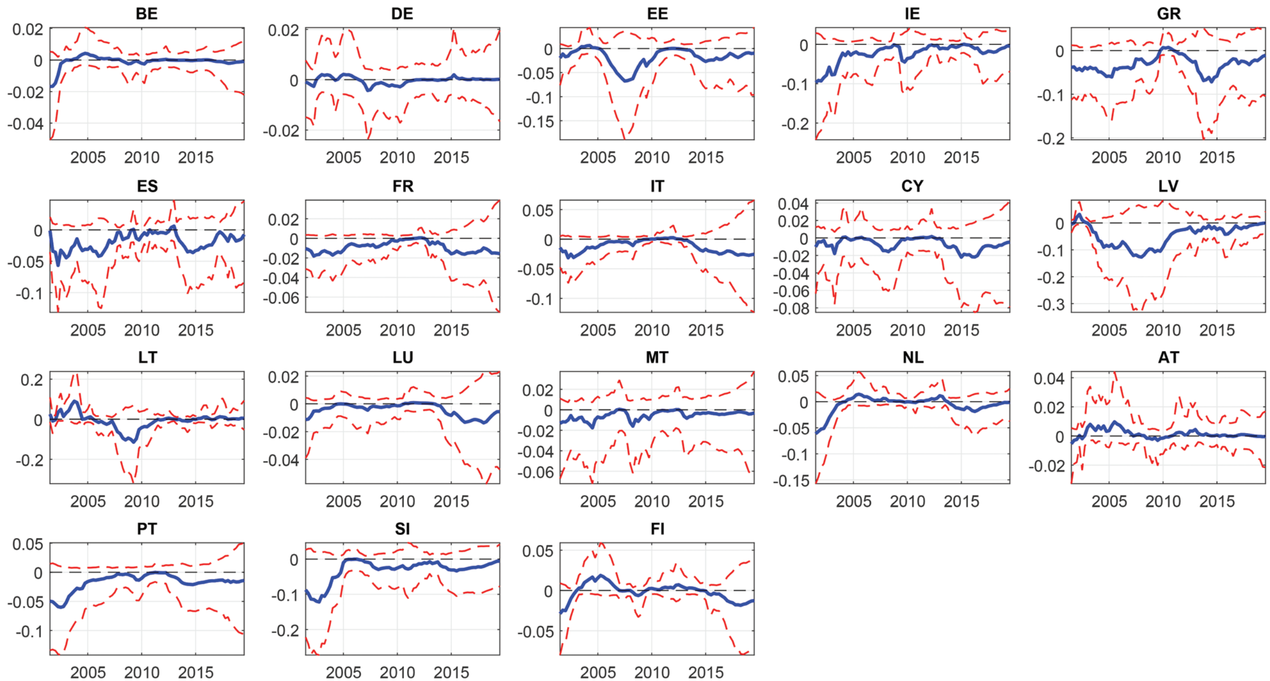


Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area core quarterly inflation expressed in percentage points.

also the case when assessing the effect of the shocks on aggregate euro-area core inflation, proxied by the extracted common factor (see Figure 8A). Also, Figure 8B shows that the persistence of core inflation has remained steady. As expected, the pattern of core inflation co-movement across countries is more heterogeneous than in the case of headline inflation, which is inferred from the estimated time-varying factor loadings shown in Figure 9. Although some countries, such as Italy or France, have displayed increasing degree of co-movement, most countries have shown a relatively stable or even decreasing pattern, as in the case of Latvia.

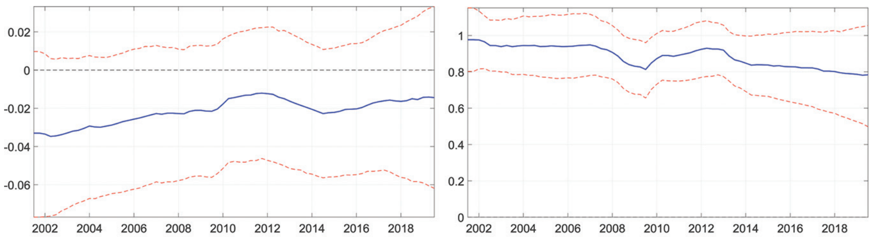
Next, with regard to food and energy subcomponents of inflation, Figures 10 and 11 show their estimated inflation factors, along with the corresponding euro-area aggregate inflation. Similar to the case of headline inflation, the path is one of striking accord. The increase in the effect of exchange rate shocks on inflation, occurred since 2010, has been significant for food prices (see Figure 12). However, it has been rather weak and more uncertain for energy inflation (see Figure 13). The degree and development of co-movement experienced by food and energy inflation rates have been relatively similar, as shown

Figure 7. Sensitivity of Country-Specific Core Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\tilde{\beta}_{i,2,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 8. Time-Varying Coefficients of Model for Core Inflation



A. Sensitivity of Core Inflation of the Euro Area (λ_t) B. Persistence of the Euro-Area Core Inflation Factor (ϕ_t)

Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

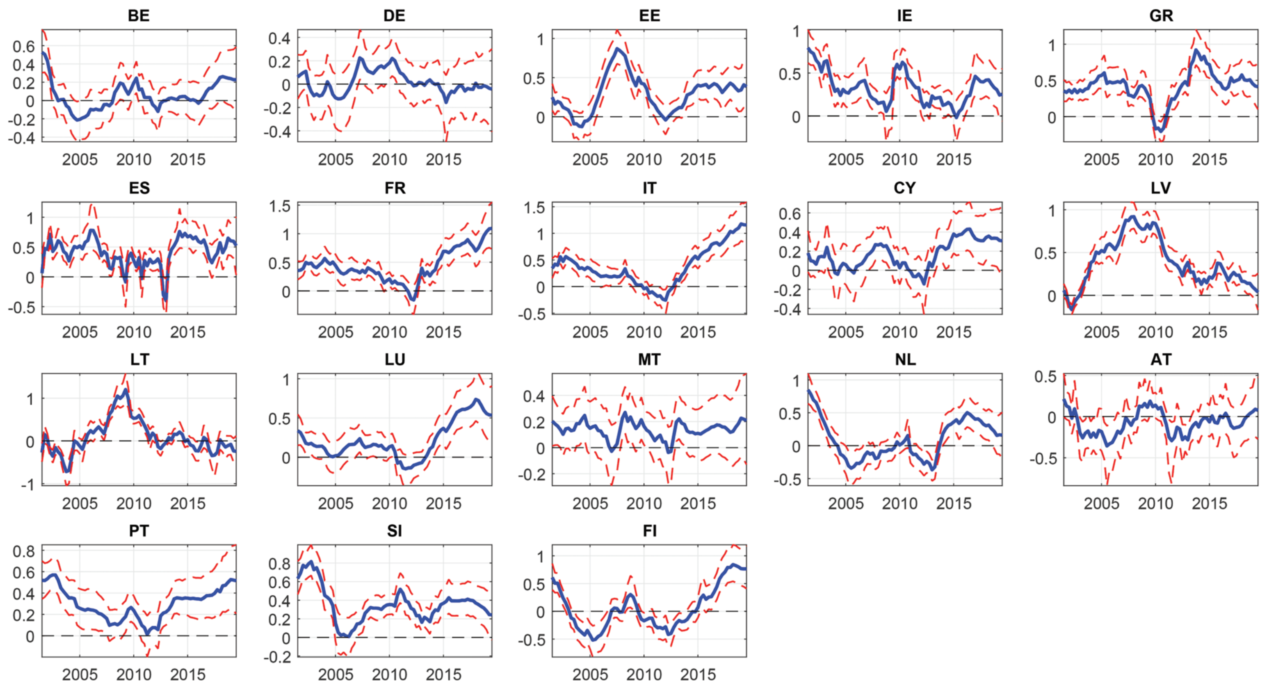
in Figures 14 and 15. Therefore, the difference between the sensitivity of food and energy inflation relies on the impact that exchange rate shocks have on the corresponding euro-area aggregates, that is, the *regionwide* component.[23]

Based on the findings obtained with the multivariate framework in Equations (5)–(9), it is important to emphasize that both *country-specific* and *regionwide* channels of the ERPT are relevant, and their relative importance largely depends on the type of price component. Also note that an important feature of the proposed multivariate framework is that it is able to both estimate and decompose the sensitivity of inflation to exchange rate shocks. Such a decomposition could be extremely useful for policymakers. It provides a timely assessment of movements in inflation in a given country—brought about by exchange rate shocks—disentangling whether they are mainly driven by the country's exclusive and intrinsic economic performance, by the overall performance of all monetary union partners, or by a combination of both.[24]

[23] Thus, the effect of exogenous exchange rate shocks on euro-area food inflation has not changed substantially over time, but the sensitivity of aggregate energy inflation to unexpected exchange rate movements has increased considerably since 2009, as shown in Figures 16A and 17A, respectively.

[24] This type of decomposition is in line with that proposed by Ozdagli and Weber (2017) based on spatial autoregressions. In particular, the authors focus on decomposing the total effect of monetary policy shocks on a given asset price

Figure 9. Time-Varying Co-movement of Euro-Area Countries' Core Inflation ($\gamma_{i,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 10. Euro-Area Food-Related Inflation Factor (f_t)

Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area food-related quarterly inflation expressed in percentage points.

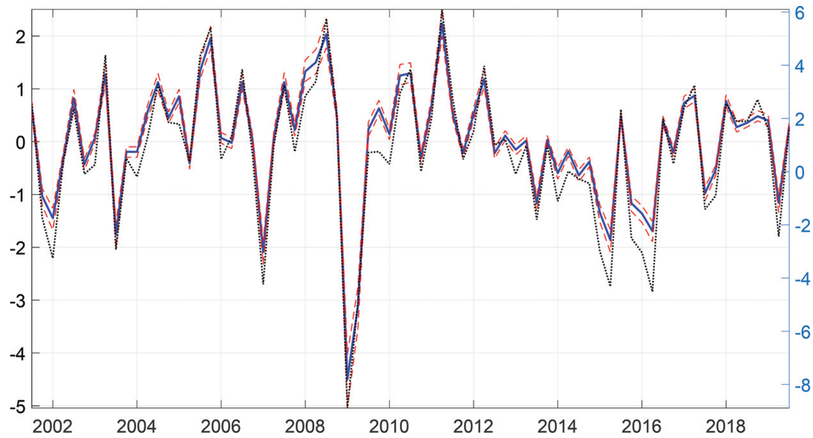
The entire set of empirical results are summarized in Table 1. They suggest that the gradual increase of the EPRT to headline inflation over time can be mainly attributed to its energy component. Across euro-area countries, the energy component is highly influenced by global factors such as oil and other commodity prices. Hence, the increasing influence of global factors in recent years could explain the increasing interlinkages between the energy inflation across euro-area economies, yielding a higher sensitivity of headline inflation to exogenous exchange rate shocks.

3.4 Robustness

In order to verify that the ERPT dynamics across countries estimated using the proposed multivariate framework do not represent an artifact solely driven by the degree of co-movement, measured by the time-varying factor loadings, we perform a robustness exercise

into (i) a *direct effect*, which would be the equivalent of our *country-specific* component; and (ii) an *indirect effect*, which takes into account the joint interaction of that given asset with the other assets in the economy, i.e., the network effect, which could be interpreted as our *regionwide* component.

Figure 11. Euro-Area Energy-Related Inflation Factor (f_t)



Note: Blue solid (red dashed) line, aligned with the left axis, makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model. Black dotted line, aligned with the right axis, makes reference to the euro-area energy-related quarterly inflation expressed in percentage points.

that omits any information on inflation co-movement in the euro area. In particular, we estimate the effect of exchange rate shocks on inflation for each country, independently, based on the following univariate regression model subject to parameter time variation:

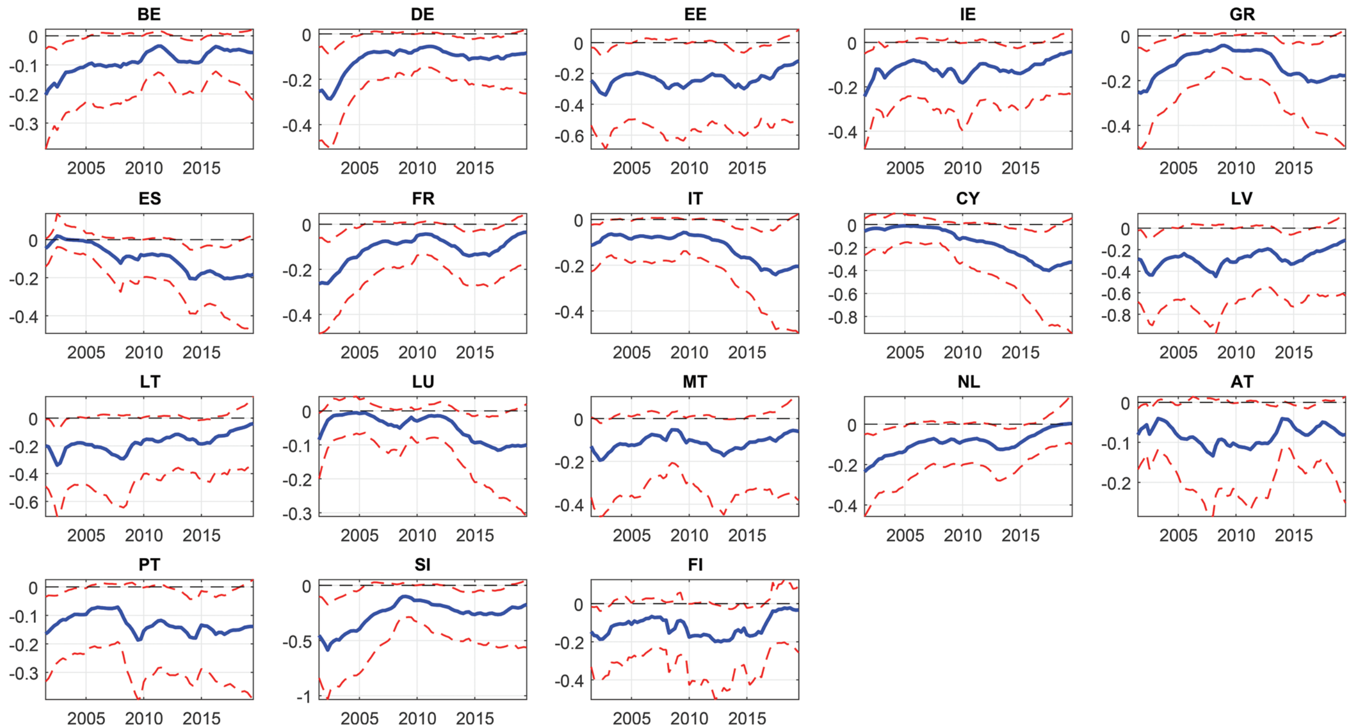
$$\pi_{i,t} = \hat{\phi}_{i,t}(L)\pi_{i,t-1} + \hat{\beta}_{i,t}\epsilon_t^{ER} + \hat{v}_{i,t}, \tag{11}$$

for $i = 1, 2, \ldots, n$, and where the element of interest is given by the dynamics of the ERPT coefficient $\hat{\beta}_{i,t}$.[25]

The estimated time-varying ERPT across countries associated with headline inflation is plotted in Figure B.4 of Online Appendix B to save space. The findings indicate that the ERPT obtained from the univariate models closely tracks the dynamics of the ERPT

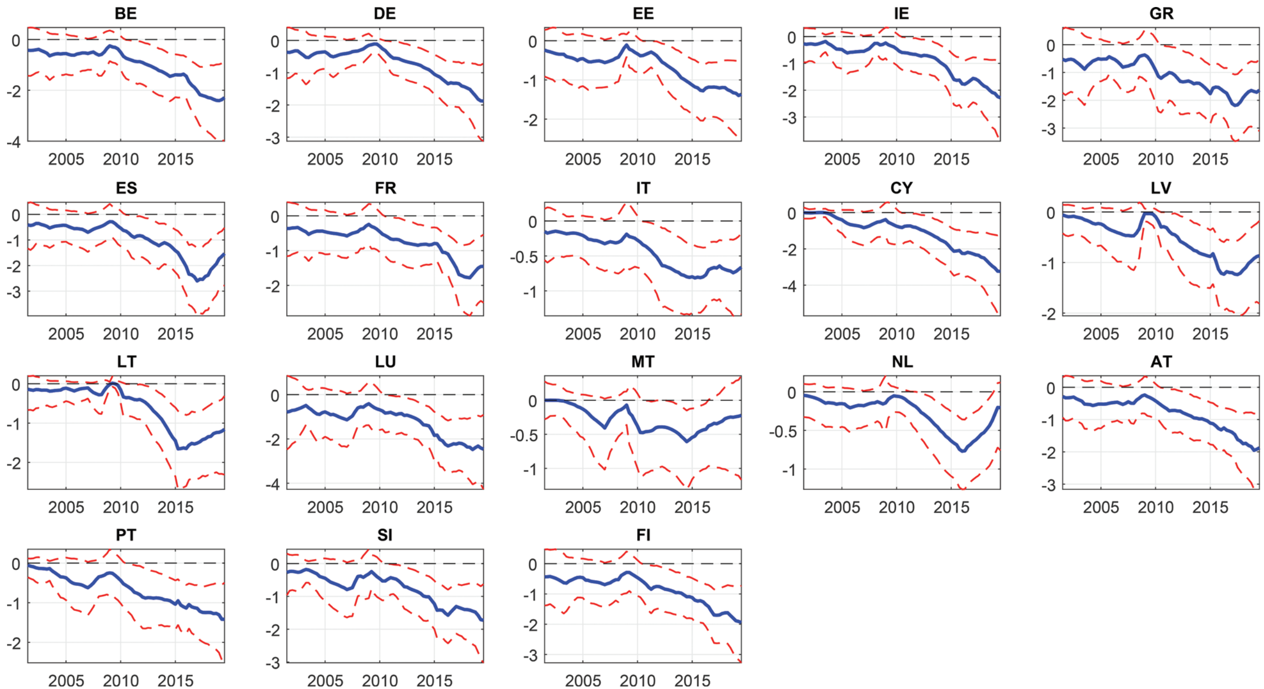
[25]Each univariate time-varying parameter regression is estimated independently with Bayesian methods, assuming $L = 1$ for consistency with the multivariate approach. The estimation algorithm follows the corresponding simplified version of the one described in Section A.1 of the online appendices, and follows the same number of Gibbs sampling iterations and corresponding priors.

Figure 12. Sensitivity of Country-Specific Food-Related Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\tilde{\beta}_{i,2,t}$)



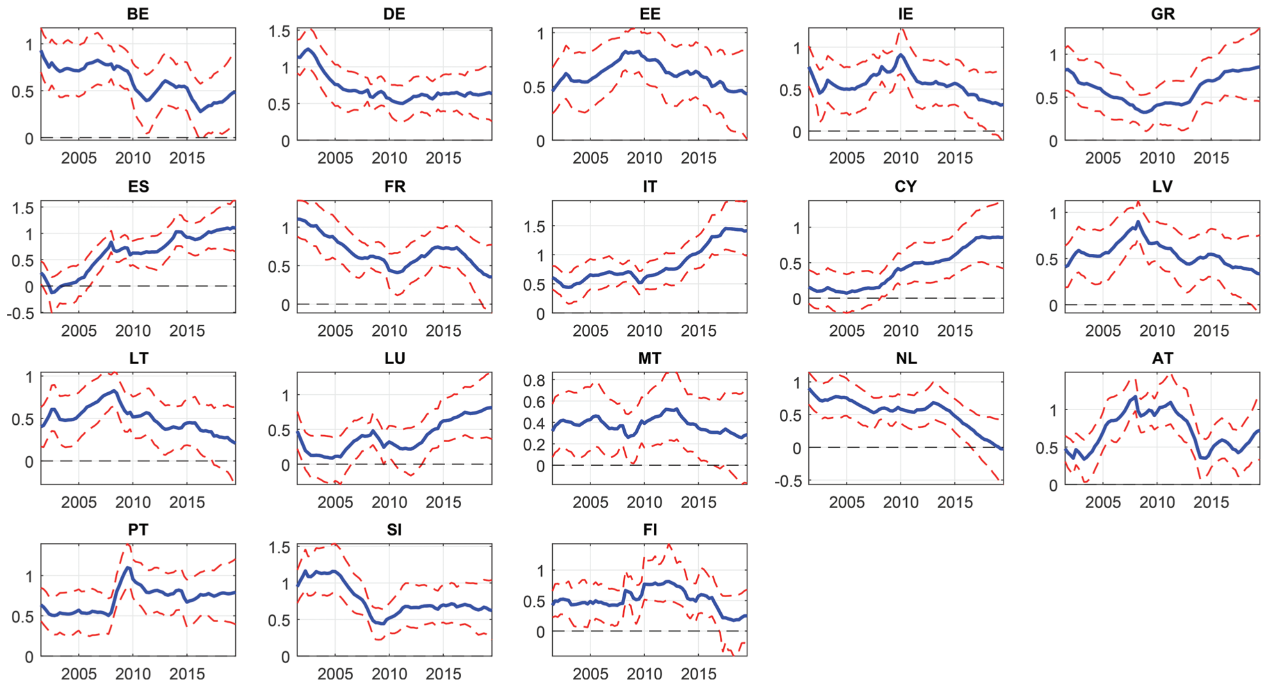
Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 13. Sensitivity of Country-Specific Energy-Related Inflation to Exchange Rate Shocks Based on a Multivariate Model ($\tilde{\beta}_{i,2,t}$)



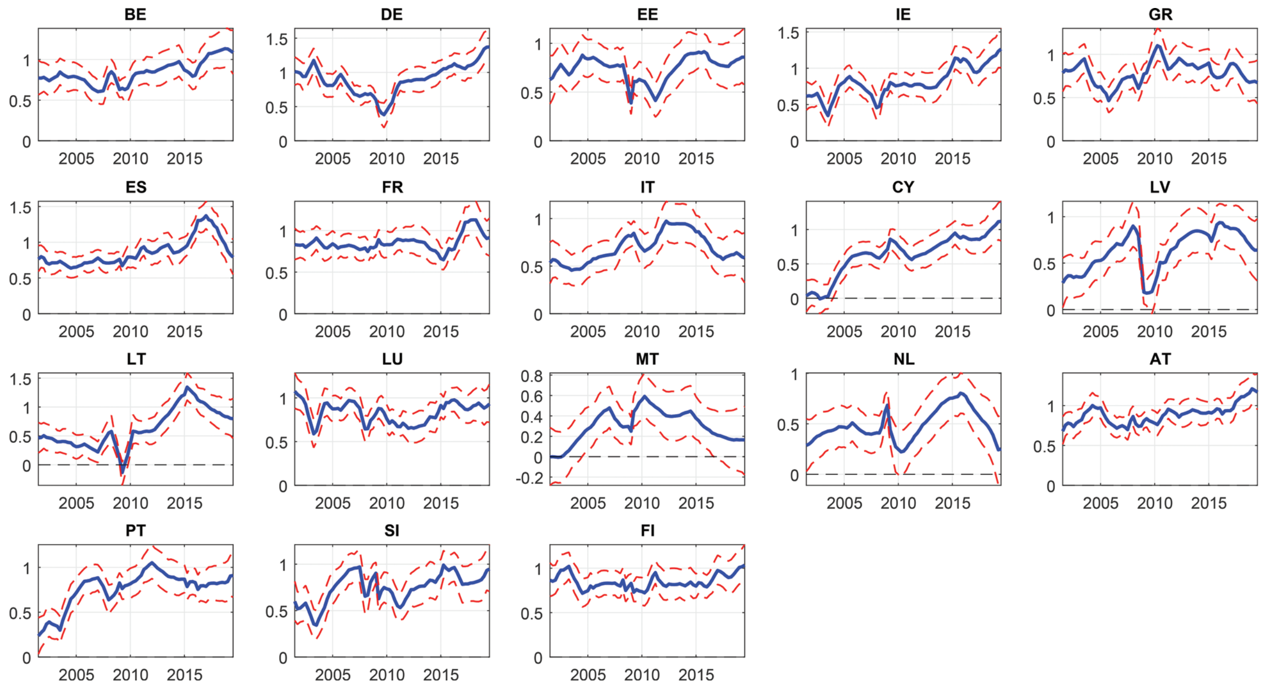
Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 14. Time-Varying Co-movement of Euro-Area Countries' Food-Related Inflation ($\gamma_{i,t}$)



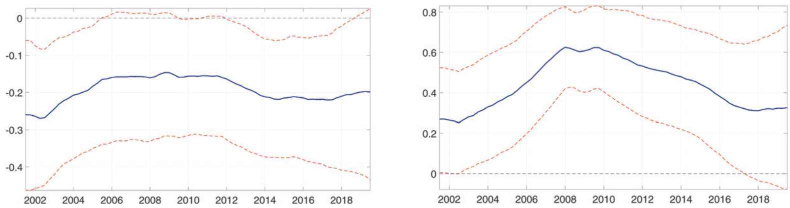
Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 15. Time-Varying Co-movement of Euro-Area Countries' Energy-Related Inflation ($\gamma_{i,t}$)



Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

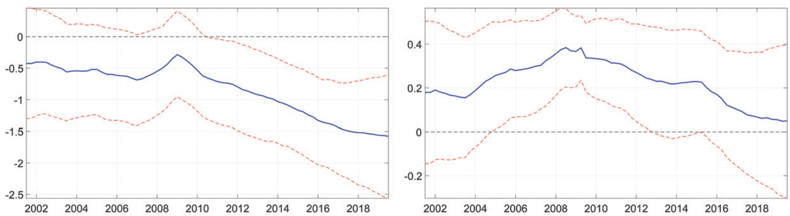
Figure 16. Time-Varying Coefficients of Model for Food-Related Inflation



A. Sensitivity of Food-Related Inflation of the Euro Area (λ_t) B. Persistence of the Euro-Area Food-Related Inflation Factor (ϕ_t)

Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Figure 17. Time-Varying Coefficients of Model for Energy-Related Inflation



A. Sensitivity of Energy-Related Inflation of the Euro Area (λ_t) B. Persistence of the Euro-Area Energy-Related Inflation Factor (ϕ_t)

Note: Blue solid (red dashed) line makes reference to the median (16th and 84th percentile) of the posterior distribution estimates obtained with the univariate model.

Table 1. Summary of Exchange Rate Pass-Through to Inflation

	Headline	**Core**	**Food**	**Energy**
Total Pass-Through	√	—	—	√
Country-Specific Component	√	—	—	√
Regionwide Component	—	—	—	√

Note: The table summarizes the main results from the empirical analysis. An entry with "√" indicates that there has been a significant increase in the total exchange rate pass-through, or its components, to the corresponding type of inflation. An entry with "—" indicates that there has not been a significant increase in the total exchange rate pass-through, or its components, to the corresponding type of inflation.

obtained from the proposed multivariate approach. This is the case for almost all the euro-area countries, with the only exceptions being Malta and Finland. In the case of core inflation, although the estimates obtained from the two approaches do not always look similar, the ERPT estimates from the univariate models point to the same message as that provided by the multivariate model, which is that the sensitivity of core inflation to exchange rate shocks tends to be of a smaller magnitude and, more importantly, the estimates tend to be more uncertain (Figure B.5).[26] Lastly, regarding the food and energy subcomponents of headline inflation, the estimates from univariate models also follow a similar path to the estimates from the multivariate model, as shown in Figures B.6 and B.7, respectively. These findings evidence that while independent univariate regressions can only measure the degree of sensitivity of euro-area countries' inflation to exogenous exchange rate shocks, the proposed factor model is able to perform the same task, while also providing a decomposition of such sensitivity into *country-specific* and *regionwide* effects.

4. Concluding Remarks

This paper proposes an innovative approach that should improve our ability to assess the effect of exchange rate fluctuations on prices across countries—especially from a time-varying and cross-country unified perspective—and by taking into account the source of exchange rate changes.

To this end, we decompose into a country-specific and regionwide component the time-varying effect that unexpected movements in the EUR/USD nominal exchange rate have on different measures of inflation in the euro-area countries. Of all the sources of exchange rate fluctuations, this paper focuses only on exogenous exchange rate shocks. This is partly because we seek to imitate insofar as possible the concept of exchange rate pass-through in a shock-dependent context: we isolate the transmission to prices of "pure" exchange

[26]When adding information on lagged shocks as additional explanatory variables in Equation (11), we find that the associated time-varying coefficients are not statistically significant. This is the case for both headline and core inflation rates. These results are not shown for the sake of space, but are available upon request.

rate shocks from the joint reaction of prices and exchange rates to other structural shocks such as demand, supply, or monetary policy shocks.

We propose an econometric framework that relies (i) on an SVAR model to identify purely exogenous exchange rate shocks; and (ii) on a dynamic factor model subject to drifting coefficients and exogenous information to identify the pass-through to inflation of such exogenous exchange rate shocks. The estimates suggest that exogenous shocks to the EUR/USD are paramount. They are behind more than 50 percent of the nominal EUR/USD exchange rate fluctuations in more than a third of the quarters of the past six years, especially in turning-point periods.

Our main findings indicate that headline inflation, and in particular its energy component, has become significantly more affected by these exogenous exchange rate shocks since the early 2010s, especially in the largest economies of the region. While in the case of headline inflation this increasing sensitivity is solely reliant on a sustained surge in the degree of co-movement, in the case of energy inflation it is also based on a higher regionwide effect of the shocks. The effect of exogenous exchange rate shocks in food inflation is similar to, but much lower than, the impact on headline inflation. By contrast, purely exogenous shocks do not seem to have a significant effect on the core component of headline inflation, which also displays a lower degree of co-movement across euro-area countries.

The information obtained with this type of decomposition can be useful for policymakers to understand the extent to which movements in inflation of a given country, brought about by exchange rate shocks, can be attributed to its exclusive and intrinsic economic performance or to the overall performance of all monetary union partners. In particular, the documented sustained surge in the degree of inflation co-movement would represent a favorable feature for the conduct of monetary policy.

The framework described here is not intended or able to capture structural differences across countries that are key to explaining different impacts of exchange rate movements, such as the role of invoicing currency, whether the transactions take place between or within firms, the frequency and dispersion of price adjustments, integration in global value chains, or the role of competition in final product markets, but it still adds an important new dimension to the standard approach for analyzing ERPT. Decomposing the effect of pure exogenous exchange rate shocks on euro-area countries' inflation into country-specific (*idiosyncratic*) and regionwide (*common*) components from a time-varying perspective should improve our understanding, to allow us to better assess the impact of currency movements and, as a result, help central banks set appropriate monetary policy.

References

Amiti, M., O. Itskhoki, and J. Konings. 2016. "International Shocks and Domestic Prices: How Large are Strategic Complementarities?" NBER Working Paper No. 22119.

Arias, J. E., J. F. Rubio-Ramirez, and D. F. Waggoner. 2018. "Inference Based on SVARs Identified with Sign and Zero Restrictions: Theory and Applications." *Econometrica* 86 (2): 685–720.

Benkovskis, K., D. Kulikov, D. Paula, and L. Ruud. 2009. "Inflation in the Baltic Countries." *Kroon & Economy* (1/2): 6–54.

Berger, D., and J. Vavra. 2013. "Volatility and Pass-through." NBER Working Paper No. 19651.

Campa, J., and L. Goldberg. 2005. "Exchange Rate Pass-through into Import Prices." *Review of Economics and Statistics* 87 (4): 679–90.

———. 2010. "The Sensitivity of the CPI to Exchange Rates: Distribution Margins, Imported Inputs, and Trade Exposure." *Review of Economics and Statistics* 92 (2): 392–407.

Ciccarelli, M., and B. Mojon. 2010. "Global Inflation." *Review of Economics and Statistics* 92 (3): 524–35.

Cœuré, B. 2017. "The Transmission of the ECB's Monetary Policy in Standard and Non-standard Times." Speech at the workshop on Monetary Policy in Non-standard Times, Frankfurt, September 11.

Coibion, O., Y. Gorodnichenko, and M. Ulate. 2017. "The Cyclical Sensitivity in Estimates of Potential Output." NBER Working Paper No. 23580.

Comunale, M., and D. Kunovac. 2017. "Exchange Rate Pass-through in the Euro Area." ECB Working Paper No. 2003.

Corsetti G., L. Dedola, and S. Leduc. 2008. "High Exchange-rate Volatility and Low Pass-through." *Journal of Monetary Economics* 55 (6): 1113–28.

De Walque, G., P. Jeanfils, T. Lejeune, Y. Rychalovska, and R. Wouters. 2017. "An Estimated Two-country EA-US Model with Limited Exchange Rate Pass-through." Working Paper No. 317, Banque Nationale de Belgique.

De Walque, G., T. Lejeune, A. Rannenberg, and R. Wouters. 2020. "Low Pass-through and High Spillovers in NOEM: What Does Help and What Does Not." Working Paper No. 386, Banque Nationale de Belgique.

Del Negro, M., and C. Otrok. 2007. "99 Luftballons: Monetary Policy and the House Price Boom across U.S. States." *Journal of Monetary Economics* 54 (7): 1962–85.

Devereux, M., B. Tomlin, and W. Dong. 2015. "Exchange Rate Pass-through, Currency of Invoicing and Market Share." NBER Working Paper No. 21413.

Dornbusch, R. 1987. "Exchange Rates and Prices." *American Economic Review* 77 (1): 93–106.

Ductor, L., and D. Leiva-Leon. 2016. "Dynamics of Global Business Cycle Interdependence." *Journal of International Economics* 102 (September): 110–27.

Eggertsson, G. B., N. R. Mehrotra, and J. A. Robbins. 2019. "A Model of Secular Stagnation: Theory and Quantitative Evaluation." *American Economic Journal: Macroeconomics* 11 (1): 1–48.

Eggertsson, G. B., N. R. Mehrotra, and L. H. Summers. 2016. "Secular Stagnation in the Open Economy." *American Economic Review* 106 (5): 503–7.

Estrada, A., L. Guirola, I. Kataryniuk, and J. Martinez-Martin. 2020. "The Use of BVARs in the Analysis of Emerging Economies." Occasional Paper No. 2001, Banco de España.

Forbes, K., I. Hjortsoe, and T. Nenova. 2015. "The Shocks Matter: Improving Our Estimates of Exchange Rate Pass-through." Discussion Paper No. 43, External MPC Unit, Bank of England.

———. 2018. "The Shocks Matter: Improving Our Estimates of Exchange Rate Pass-through." *Journal of International Economics* 114 (September): 255–75.

Gopinath, G., O. Itskhoki, and R. Rigobon. 2010. "Currency Choice and Exchange Rate Pass-through." *American Economic Review* 100 (1): 304–36.

Hahn, E. 2003. "Pass-through of External Shocks to Euro Area Inflation." Working Paper No. 0243, European Central Bank.

Jašová, M., R. Moessner, and E. Takáts. 2016. "Exchange Rate Pass-through: What Has Changed Since the Crisis?" BIS Working Paper No. 583.

Kilian, L. 2009. "Not All Oil Price Shocks Are Alike: Disentangling Demand and Supply Shocks in the Crude Oil Market." *American Economic Review* 99 (3): 1053–69.

Krippner, L. 2013. "Measuring the Stance of Monetary Policy in Zero Lower Bound Environments." *Economics Letters* 118 (1): 135–38.

Krugman, P. 1987. "Pricing to Market when the Exchange Rate Changes." In *Real-Financial Linkages Among Open Economies,* ed. S. W. Arndt and D. J. Richardson. Cambridge, MA: MIT Press.

Leiva-Leon, D. 2017. "Monitoring the Spanish Economy through the Lenses of Structural Bayesian VARs." Occasional Paper No. 1706, Banco de España.

Mumtaz, H., and L. Sunder-Plassmann. 2013. "Time-varying Dynamics of the Real Exchange Rate: An Empirical Analysis." *Journal of Applied Econometrics* 28 (3): 498–525.

Ortega, E., and C. Osbat. 2020. "Exchange Rate Pass-through in the Euro Area and EU Countries." ECB Occasional Paper No. 241.

Ozdagli, A., and M. Weber. 2017. "Monetary Policy through Production Networks: Evidence from the Stock Market." NBER Working Paper No. 23424.

Özyurt, S. 2016. "Has the Exchange Rate Pass Through Recently Declined in the Euro Area?" ECB Working Paper No. 1955.

Shambaugh, J. 2008. "A New Look at Pass-through." *Journal of International Money and Finance* 27 (4): 560–91.

Wu, J. C, and D. F. Xia. 2016. "Measuring the Macroeconomic Impact of Monetary Policy at the Zero Lower Bound." *Journal of Money, Credit and Banking* 48 (2–3): 253–91.

Applying Lessons from the Past? Exploring Historical Analogies in ECB Speeches through Text Mining, 1997–2019*

Anselm Küsters
Max Planck Institute for Legal History and Legal Theory

By employing text mining methods such as structural topic modeling to examine all 2,135 speeches by ECB Executive Board members between February 1997 and October 2019, this paper identifies and analyzes a significant semantic change that occurred in ECB communication in the transition from the Great Moderation to the Great Recession. The methodology also allows for a structured and empirical assessment of the hypothesis that central bankers used "lessons from the past" during the crisis. The quantitative and qualitative results indicate that references to historical analogies indeed increased at the height of the crisis (2009–11) but often served only rhetorical functions.

JEL Codes: B29, C89, E58, N14.

*For their helpful comments on earlier versions of this paper and generous support during the publication process, I would like to thank Catherine Schenk, Stefano Battilossi, Stefan Vogenauer, Victoria Barnes, Donal Coffey, Philip Bajon, Andrea Ramazzotti, and Maria Eskelinen. I am also grateful to the two anonymous reviewers, whose detailed feedback has improved my analysis significantly, and to Sharon Kozicki for her professional guidance throughout the editorial process. A special thanks goes to the participants at the conference "Uses of the Past in International Economic Relations" at St. Hilda's College, Oxford, where I presented some of the preliminary results in May 2019. Finally, I am grateful to the UPIER team for publishing an earlier version of this work, entitled "Applying Lessons of the Past? Exploring ECB Speeches during the Great Recession," in their working paper series. For more information on the UPIER project, see https://upier.web.ox.ac.uk. A more recent version of this paper can be found in the Max Planck Institute for Legal History and Legal Theory Research Paper Series on SSRN: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3861671.
The author can be contacted via kuesters@lhlt.mpg.de.

1. Introduction: Applying Lessons from the Past?

When the financial crisis of 2007 erupted, the limitations of mainstream economic models soon became apparent. Jean-Claude Trichet, then president of the European Central Bank (ECB), found the available models of limited help: “In the face of the crisis,” he reported during an opening address in November 2010, “we felt abandoned by conventional tools.” In the absence of clear guidance from existing analytical frameworks, one area of literature promised help: historical analysis. “Historical studies of specific crisis episodes highlighted potential problems which could be expected. And they pointed to possible solutions. Most importantly, the historical record told us what mistakes to avoid” (Trichet: November 18, 2010).[1]

Trichet’s reflections were by no means an outlier. Following the crisis’s outbreak, numerous observers used references to the Great Depression and the lessons that might be learned (e.g., Eichengreen and O’Rourke 2010; Ritschl 2012; Hesse, Köster, and Plumpe 2015, pp. 205–16; Eichengreen 2016). In his influential monograph, Eichengreen (2015) argues that during this period of crisis, a repeat of the 1930s was avoided because central bankers and politicians recognized the Great Depression’s lessons regarding monetary and fiscal policy. Indeed, a whole generation of macroeconomists that influenced or commented on policy during this period, including Larry Summers, Paul Krugman, Ben Bernanke, Peter Temin, Bradford DeLong, and Christina Romer, had been influenced by Charles Kindleberger at the Massachusetts Institute of Technology to think they could learn from the Great Depression (Hansen 2019, p. 169). However, while applying historical lessons prevented the worst in 2008, Eichengreen (2015) argues, this ironically increased the duration of the Great Recession because large monetary and fiscal stimuli reduced the perceived need for subsequent reforms. By contrast, stimuli measures in the 1930s had been accompanied by substantial banking reforms. In effect, Eichengreen thus argues that those responsible only applied *certain* lessons while ignoring others.

[1]References to ECB speeches that are included in the corpus are displayed in the main text and abbreviated with name of speaker and full date, but not listed separately in the References.

The argument that economic history played an important role in central bank action and communication during the crisis is largely based on sparse and anecdotal evidence. This paper, in contrast, carries out a structured and empirical assessment of the semantic change that occurred in ECB communication in the transition from the Great Moderation to the Great Recession. To do so, it examines all 2,135 speeches by ECB Executive Board members between February 1997 and October 2019, which also allows for a more nuanced, dynamic analysis of the extent to which policymakers applied historical analogies. In particular, the occurrence of such analogies is examined through the estimation of a structural topic model, frequency plots of key bigrams and dates, as well as manual classification of speeches. The quantitative and qualitative results indicate that references to historical analogies increased at the height of the crisis (2009–11) but often served only rhetorical functions.

This paper contributes to a growing literature that analyzes central bank communication, which has become an important monetary policy tool since the 1990s. Scholars have found that central banks' communication can move financial markets, enhance the predictability of monetary policy, and help achieve the banks' stabilization objectives (Blinder et al. 2008). However, since the publication of Morris and Shin's (2002) influential paper, central bankers are well aware that increases in the precision of the published information can also have welfare-reducing effects. In practice, therefore, communication strategies usually improve through a trial-and-error process (Woodford 2005). This paper contributes to a better understanding of the ECB's communication process during the Great Recession by analyzing the historical analogies contained in ECB Executive Board members' speeches. Since the literature suggests that central bank communication should be focused on topics closely related to monetary policy (Blinder et al. 2008), identifying the presence of complex and contested "lessons from the past" raises the question of whether the latter constitute "noise" that ultimately reduces the predictability, effectiveness, but also general accessibility (Haldane and McMahon 2018) of monetary policy decisions.

The following analysis rests on new text mining methods (overview: Bholat et al. 2015) and thus contributes in particular to a subset of this economics literature that aims to quantify central banks' communication through means of natural language processing (e.g., Masawi, Bhattacharya, and Boulter 2014; Hansen and McMahon 2016; Hansen, McMahon, and Prat 2018; Takeda and Keida 2018; Hansen, McMahon, and Tong 2019; Hansson 2021). These computer-enabled approaches can investigate a large collection of documents ("corpus") at a scale that would be impossible by human close reading. Moreover, such approaches can extract meaning that would be overlooked by humans due to prior beliefs or expectations. It is therefore not surprising that recently, central banks' internal research departments have themselves started to use text mining methods—for instance to review the ECB's monetary policy during its first 20 years of existence (Hartmann and Smets 2018), to assess the effectiveness of forward guidance in unconventional times (Coenen et al. 2017), and to test empirically whether central banks' decisions and their justifications are communicated in clear language (Qvigstad and Schei 2018). By discussing the corpus of ECB speeches in detail and by introducing methods such as structural topic modeling that so far have been overlooked in the analysis of ECB communication, this paper aims to advance this strand of research.

The remainder of the paper is structured as follows. The first section presents and explores the ECB corpus via descriptive statistics and several text mining methods, thereby revealing significant changes in ECB communication after the outbreak of the Great Recession: the number of ECB speeches increased, their net sentiment dropped from a generally positive to a negative tone, and their semantic content changed considerably. To understand the drivers behind these trends, the following section estimates a structural topic model that allows us to capture the main topics discussed by ECB Board members and their evolution over time. Since one can detect significant semantic differences between pre- and post-crisis speeches, the second part of the paper turns to the question of whether this semantic change was accompanied by an increased usage of historical lessons, as argued by Eichengreen and others. To answer this question, the next two sections define and then analytically trace the specific historical lessons that the ECB allegedly relied on during the Great Recession. Based on the estimated topics' dynamics, a frequency analysis of key bigrams and dates as well as manual classification of key speeches, the paper concludes that although some historical lessons are echoed in ECB speeches at the height of the Great Recession, this is qualified by the small proportion of speeches that actually describe these lessons as opposed to simply mentioning them as a rhetorical device.

2. Corpus: Institutional Context and Descriptive Statistics

The corpus of ECB speeches contains the content of all speeches of ECB Executive Board members until October 11, 2019, together with limited metadata such as name of speaker and date.[2] Some of the oldest speeches predate the existence of the ECB and were given by the president of the European Monetary Institute (EMI), which was the forerunner to the ECB. Thus, the corpus starts with a speech given by Alexandre Lamfalussy, the first EMI president, on February 7, 1997. After some slight manual changes to the corpus,[3] the resulting database contains 2,135 speeches consisting of 3,114,853 words.

Before turning to the explanatory analysis, it is helpful to reflect on the nature of speeches as a source for analyzing the ECB's decisionmaking and communication strategy. Speeches provide a rich source of information (cf. Sussman, Ricchio, and Belohlav 1983, p. 188). Firstly, a speech captures the concerted effort of a writer aiming to deliver a meaningful statement. Secondly, a speech

[2]For a preliminary version of this paper, all speeches that were given by members of the ECB's Executive Board between January 1, 2007 and December 31, 2015 were downloaded from the bank's digital archive and manually stored in a single file. When this paper was prepared for final publication in October 2019, the ECB released a precompiled data set containing the content of all ECB speeches on its website, together with some metadata. However, speeches given at the time of the European Monetary Institute (1997–98) are not complete. In order to facilitate comparisons with related work in the field of central bank communication, the final version of this paper relies on this publicly available data set. Source: European Central Bank, Speeches data set. Retrieved from https://www.ecb.europa.eu/press/key/html/downloads.en.html (accessed October 25, 2019).

[3]First, all non-English speeches were dropped in order to enable the later text mining exercises. Second, all observations that merely referred to PowerPoint slides instead of transcribed speeches were likewise dropped. Third, a speech jointly held by Willem F. Duisenberg and Eugenio Domingo Solans on August 30, 2001 was dropped so that every speech could be linked to a single speaker. Finally, the speakers' names within the texts were removed.

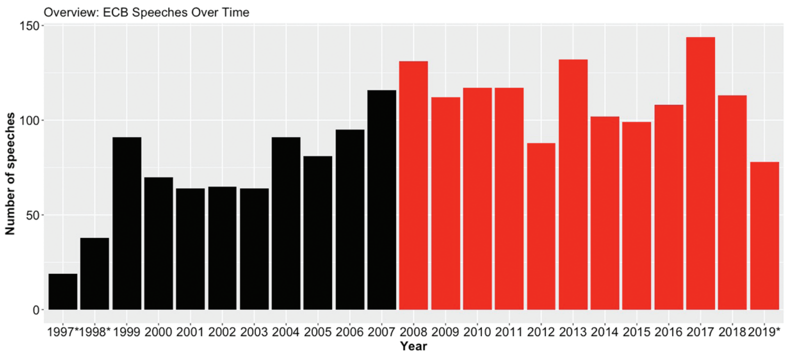
addresses an issue deemed important enough to consume time of an ECB Executive Board member. Thirdly, it is reasonable to assume that digitally available speeches are formally sanctioned by the ECB, meaning that they convey the institution's official position in an attempt to inform, persuade, or reinforce the beliefs of a given audience. Although devoted to a particular audience and occasion, speeches are, fourthly, indirectly addressed to a mass audience, and Board members are undoubtedly aware of this potential.

However, one has to keep in mind that central bankers follow certain communication rules that can be limiting. Most importantly, they have strong incentives to avoid dramatizing communication with the public. Central bankers try to manage expectations in an attempt to ensure the effectiveness of monetary policy, and their speeches are consciously developed to substantiate a given position. Additionally, the oral delivery influences these texts' length, size, and language (Volkens et al. 2013, p. 153). In short, ECB speeches are no objective display of the speaker's underlying thoughts but aim to influence the public's expectations.

Addressing the internal decisionmaking processes more directly would require access to source material that is currently not available. Particularly the internal memos and other declassified statements that have been shown to be particularly helpful in tracing the uses of the past (Neustadt and May 1986) are usually not accessible to scholars analyzing contemporary events. By contrast, today's public sources such as ECB speeches are available in an electronic machine-readable format that allows scholars to analyze them quantitatively in the hope that this aggregate approach can shed light on underlying preferences of these actors. Moreover, even if results derived from publicly available sources are biased by the central bank's communication strategy, it is important to know whether this strategy presents the past as a foundation of central bankers' decisions and, if so, how it discriminates among different historical experiences of member states. As an analysis of the narrative elements of ECB communication, the following results illuminate the ECB's framing of the crisis.

The remainder of this section explores the ECB corpus first via different basic descriptive statistics, followed by more sophisticated text mining methods. As will become clear, the outbreak of the Great Recession changed ECB communication significantly: the number of

Figure 1. The Corpus of ECB Speeches Given between February 1997 and October 2019, Plotted Over Time



Source: ECB corpus; see description in the main text.
Note: Since 1997, 1998, and 2019 feature only partial observations, they are not directly comparable and thus marked with an asterisk.

ECB speeches increased, their net sentiment dropped from a generally positive to a negative tone, and their semantic content changed considerably. To begin with, it is worth emphasizing that this corpus does not constitute a *sample* of ECB speeches, but rather captures the whole *population* of speeches since the ECB replaced the EMI on June 1, 1998. This means that the corpus does not suffer from any form of sample-selection bias. Plotting this population over time reveals a significant increase in number of speeches given over time (Figure 1). One could hypothesize that this increase in semantic data was linked to the challenges arising from the Great Recession. This interpretation is supported by the findings of Coenen et al. (2017, p. 9), who find that the minutes of central bank committee meetings of a large number of central banks, including the Federal Reserve, the Bank of England, the Bank of Japan, and the Swedish Riksbank, have become significantly longer since the crisis. Similarly, Meade, Burk, and Josselyn (2015) show that the diversity of views, as measured by the minutes of the Federal Open Market Committee, has increased particularly since the financial crisis.

Differentiating according to speaker underlines that ECB presidents (Willem Duisenberg, Jean-Claude Trichet, Mario Draghi) exhibit an important public function due to the more than 100 speeches that they deliver throughout their term (Table 1). However,

Table 1. Number of ECB Speeches Given by Each Executive Board Member between February 1997 and October 2019

Speaker (Nationality)	Period	# Speeches Absolute)	# Speeches (in %)	# Months Active	Speeches/Months (Average)
Alexandre Lamfalussy (Hungarian/Belgian)	Feb. 1997–Jun. 1997	7	0.33%	5	1.4
Benoît Cœuré (French)	Feb. 2012–Sep. 2019	177	8.29%	92	1.9
Christian Noyer (French)	Nov. 1998–Apr. 2002	46	2.15%	42	1.1
Eugenio Domingo Solans (Spanish)	Dec. 1998–Apr. 2004	59	2.76%	65	0.9
Gertrude Tumpel-Gugerell (Austrian)	Jun. 2004–May 2011	136	6.37%	96	1.4
Jean-Claude Trichet (French)	Nov. 2003–Oct. 2011	318	14.89%	96	3.3
Jörg Asmussen (German)	Mar. 2012–Dec. 2013	36	1.69%	22	1.6
José Manuel González Páramo (Spanish)	Nov. 2004–May 2012	96	4.50%	91	1.1
Jürgen Stark (German)	Jul. 2006–Dec. 2011	66	3.09%	66	1.0
Lorenzo Bini Smaghi (Italian)	Oct. 2005–Dec. 2011	108	5.06%	75	1.4
Lucas Papademos (Greek)	Mar. 2003–May 2010	87	4.07%	87	1.0
Luis de Guindos (Spanish)	Jun. 2018–Oct. 2019	33	1.55%	17	1.9
Mario Draghi (Italian)	Nov. 2011–Oct. 2019	182	8.52%	96	1.9
Otmar Issing (German)	Jul. 1998–May 2006	82	3.84%	95	0.9

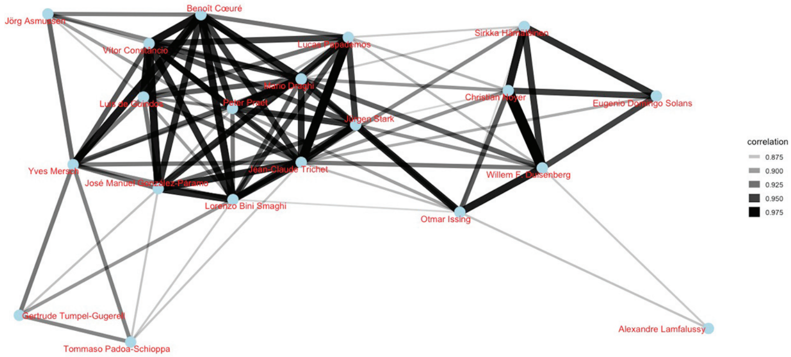
(*continued*)

Table 1. (Continued)

Speaker (Nationality)	Period	# Speeches Absolute)	# Speeches (in %)	# Months Active	Speeches/Months (Average)
Peter Praet (Belgian/German)	Jun. 2011–May 2019	118	5.53%	96	1.2
Philip R. Lane (Irish)	Jul. 2019–Oct. 2019	4	0.19%	4	1.0
Sabine Lautenschläger (German)	Feb. 2014–Jun. 2019	79	3.70%	65	1.2
Sirkka Hämäläinen (Finnish)	Oct. 1998–Apr. 2003	43	2.01%	55	0.8
Tommaso Padoa-Schioppa (Italian)	Sept. 1998–Nov. 2004	46	2.15%	75	0.6
Vitor Constâncio (Portuguese)	Jul. 2010–May 2018	125	5.85%	95	1.3
Willem F. Duisenberg (Dutch)	Jun. 1997–Oct. 2003	149	6.98%	77	1.9
Yves Mersch (Luxembourgian)	Feb. 2013–Sept. 2019	138	6.46%	80	1.7
Total		**2,135**	**100.00%**	**1,492**	**1.4**

Source: ECB corpus; see description in the main text.
Note: "Period" refers to the period during which the respective Board member gave speeches; this does not necessarily have to correspond to the official period of employment.

Figure 2. Correlation Network between ECB Executive Board Members' Speeches



Source: ECB corpus; see description in the main text.
Note: Using the phi coefficient, correlation was calculated as correlation among words, which indicates how often they appear together relative to how often they appear separately.

some Board members such as Benoît Cœuré, Yves Mersch, and Gertrude Tumpel-Gugerell have been comparably active speakers. Each member, except Philip Lane, who was the latest addition to the Board at the end of the period examined here, is represented by several dozen speeches, meaning that the results will not be driven by a single dominant speaker. The calculated statistics on average speeches per month strengthen this argument.

The impression that there is no single dominant speaker is further corroborated by the correlation network displayed in Figure 2, which quantifies how similar speakers tend to be to each other with respect to speech content (cf. Silge and Robinson 2017).[4] Rather than a high number of small clusters of speakers, one large network

[4]In order to identify speakers that are similar to each other in semantic content, one has to find the pairwise correlation of word frequencies within each speaker's speeches. Here, correlation among words indicates how often they appear together relative to how often they appear separately. On a technical level, this is done by calculating the so-called phi coefficient, a measure for binary correlation (which is equivalent to the well-known Pearson correlation when being applied to binary data). Next, one can filter for stronger correlations among speakers, and visualize them in a network, as done in Figure 2. For more details, see Silge and Robinson (2017).

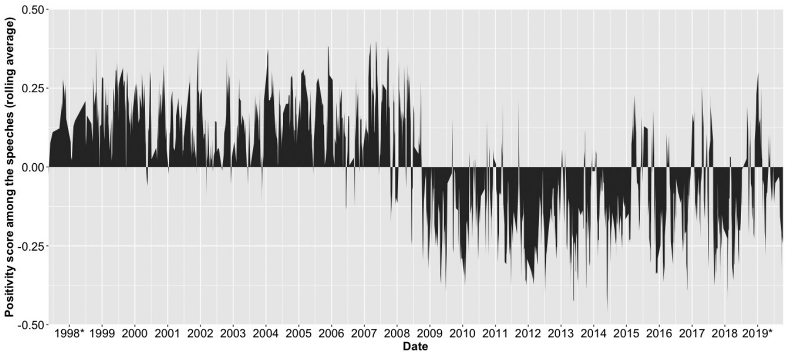
with strong correlations between almost all of the speakers emerges, indicating a strong semantic similarity between their speeches. The only speakers that do not reach the necessary threshold for inclusion in the network figure are the recently added Philip Lane as well as Sabine Lautenschläger, whose speeches are semantically very distinctive due to their almost exclusive focus on banking supervision. This strong semantic similarity reflects the speakers' belonging to a close epistemic community of global monetary policy experts with a shared vocabulary as well as the presence of an underlying overall ECB communication strategy.

Still, a closer look reveals that the high semantic correlation holds particularly for the second and third generation of Board members that can be associated with the fight against the Great Recession. In contrast, the cluster surrounding the first ECB president, Willem Duisenberg, is relatively less correlated with the rest of the speakers. This cluster is solely formed by Board members that served during the first years of Duisenberg's term such as Otmar Issing, Sirkka Hämäläinen, Christian Noyer, and Eugenio Domingo Solans as well as Alexandre Lamfalussy, the EMI's founding president.[5]

Next, the ECB corpus is explored via sentiment analysis, a method that detects emotional content of text programmatically (cf. Bholat et al. 2015, p. 8). This method assumes that the sentiment of a text can be gauged by considering the text as a combination of its individual words and the sentiment content of the whole text as the sum of the sentiment content of the individual words. One therefore needs a sentiment dictionary, i.e., a list of words that allocates sentiment scores to individual words within the text. Following everyday language, the popular Harvard IV-4 dictionaries, as used by Tetlock (2007), associate words like "tax," "cost," and "liability" with negative sentiment, although these words' tone is rather neutral in the context of financial markets. The following analysis is therefore based on the Loughran and McDonald (2011) dictionary that allocates words into six different categories (negative, positive, uncertainty, litigious, constraining, superfluous) based on the most

[5]The only exception is Tommaso Padoa-Schioppa, who finds himself in the lower left corner of the network close to Gertrude Tumpel-Gugerell, with whom he shares the responsibility for financial integration and the European payment system.

Figure 3. ECB Speeches' Sentiment Over Time (five-point rolling average)



Note: Based on the Loughran/McDonald dictionary, net sentiment is calculated for each date that featured one or more speeches by using the positivity score (as described in the main text) and then plotted over time. Since 1998 and 2019 feature only partial observations, they are not directly comparable and thus marked with an asterisk.

likely interpretation of a word in a business context. By using the Loughran/McDonald dictionary, it is taken into account that ECB speeches contain numerous financial terms, thereby ensuring that these terms are not counted as negative per se.

After classifying all tokens, one can count the number of uses of each sentiment-associated word. For instance, the positive term that occurs most often is "stability" (16,372 times), probably referring to the ECB's primary objective of price stability, whereas the most frequent negative term is "crisis" (9,744 times), which predominantly refers to the Great Recession. Using the Loughran/McDonald dictionary ensures that a frequent term like "risk" (9,991 times) is not counted as negative, but as signaling uncertainty. Based on these classifications, net sentiment is calculated for each day that featured one or several ECB speeches via the positivity score, which equals $\frac{\sum \text{positive tokens} - \sum \text{negative tokens}}{\sum \text{positive tokens} + \sum \text{negative tokens}}$.

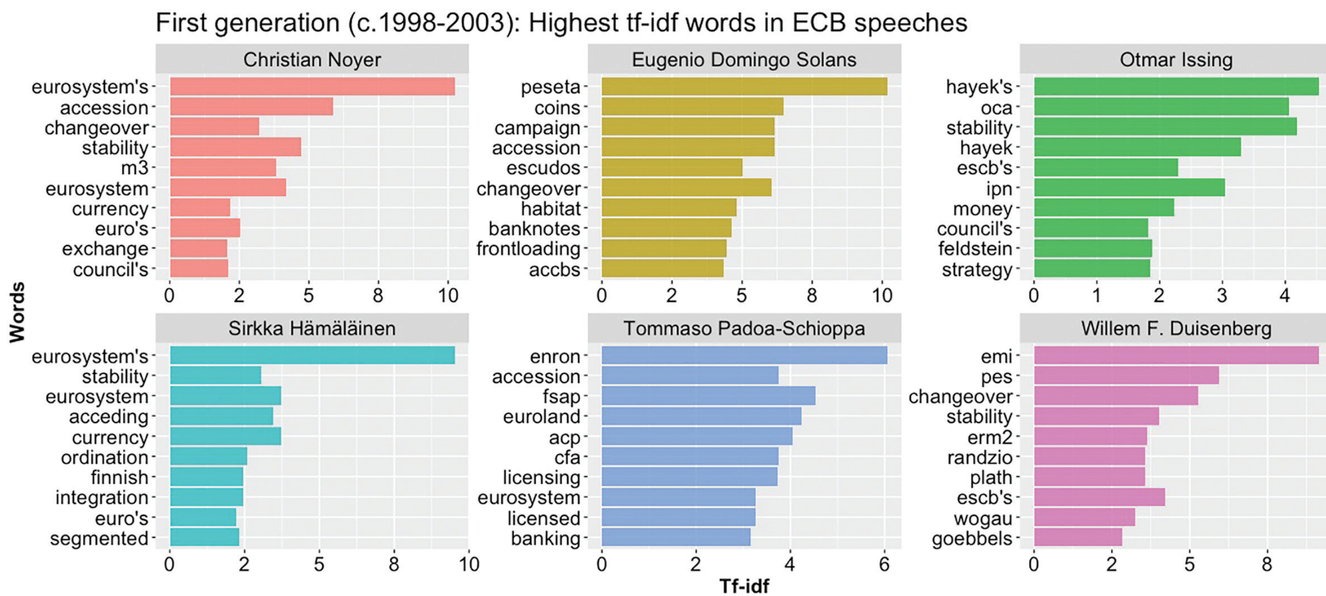
Based on these positivity scores, a rolling average of order 5 is shown, providing an approximation of the sentiment trend-cycle (Figure 3). The results make clear that throughout the Great Moderation, i.e., the first decade of the ECB's existence, ECB speeches were usually positive in tone, revealing the contemporary satisfaction with the macroeconomic climate of these days. However, starting with Lehman Brothers' bankruptcy, the positivity score declines rapidly, achieving its lowest point during 2011 when contagion spread from Greece to other southern euro-zone member states. Despite ECB President Mario Draghi's announcement that "the ECB is ready to do whatever it takes to preserve the euro" in July 2012, the index recovers only slowly and stays predominantly negative until 2018.

These findings already point towards the usage of historical lessons that will be analyzed in the second part of this paper. It is plausible that such lessons were used more often in times of crisis and that sentiment analysis can help show when these times are occurring. Indeed, Eichengreen (2015, p. 377) postulates that historical analogies are "especially influential in crises, when there is no time for reflection" and "they resonate most powerfully when an episode is a defining moment for a country and society." Given the net sentiment pattern shown above, these two psychological prerequisites for the appearance of historical lessons—sense of urgency and perceived turning point—are fulfilled for the last decade of the corpus. Thus, if the hypothesis regarding the role of historical analogies in handling a crisis situation is true, one should find historical lessons in ECB speeches during the period of the Great Recession. The later analysis will show that this was indeed the case.

In the remainder of this section and the subsequent section, more advanced text mining methods will be employed in order to substantiate the semantic change between the first and the subsequent generations of Board members. These methods share the assumption that a speech's content can be quantified by looking at the underlying words (for an overview, see Silge and Robinson 2017; also, Wickham and Grolemund 2017). Typically, researchers start by calculating each term's tf-idf (term frequency–inverse document frequency) score, the frequency of a term adjusted for how rarely it is used. This score measures how important a word is to a document in a corpus of documents (cf. Silge and Robinson 2017). One gets a good impression of the most important topics in ECB speeches by determining the highest tf-idf words that were most specific to each speaker.

Figure 4 starts by plotting the 10 highest tf-idf words for the first generation of ECB Board members consisting of then President Willem

Figure 4. The 10 Highest tf-idf Words for Each Speaker in the First Generation of ECB Executive Board Members



Source: ECB corpus; see description in the main text.
Note: This is based on calculating each term's tf-idf, which equals the frequency of a term adjusted for how rarely it is used. To enable better readability, the very low tf-idf values were scaled by a factor of 10,000. Of course, this does not change their relative size and therefore the message of this figure.

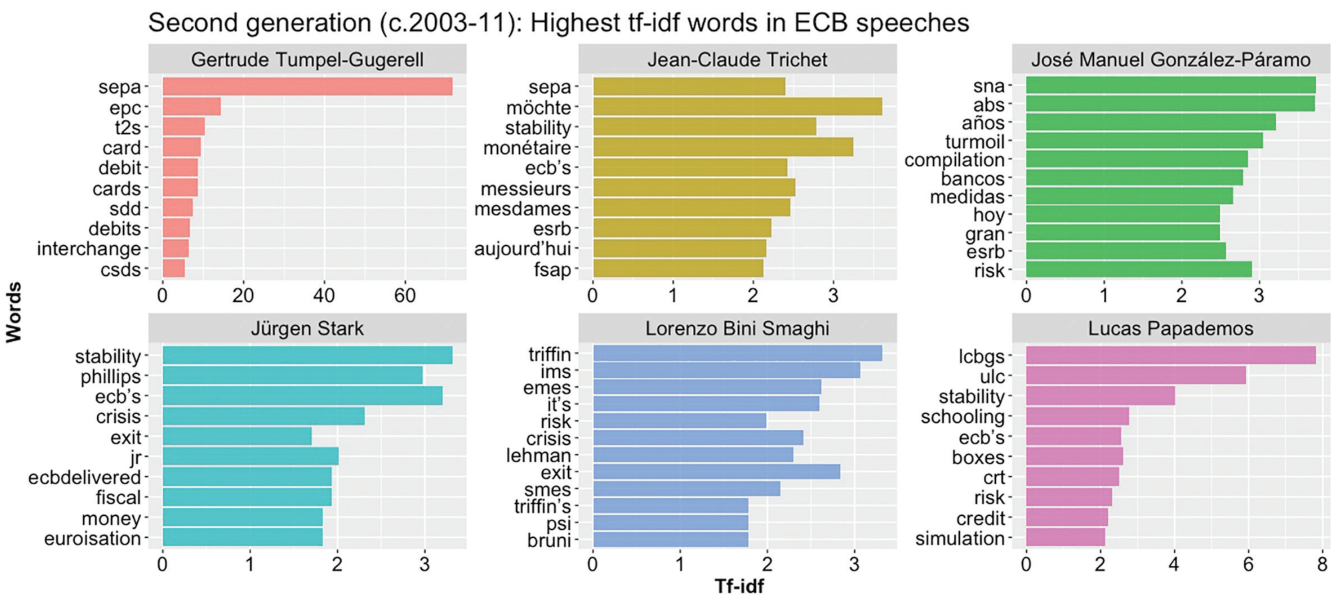
Duisenberg, his Vice President Christian Noyer as well as Otmar Issing, Tommaso Padoa-Schioppa, Sirkka Hämäläinen, and Eugenio Domingo Solans. Echoing the very beginnings of the ECB's institutional existence, terms like "accession," "changeover," and "Eurosystem" can be found multiple times. Issing, the ECB's first chief economist, was responsible for developing a monetary policy strategy in pursuit of price stability (Issing et al. 2001), and his word profile accordingly includes the term "strategy." Eventually, the ECB adopted a novel "two-pillar" strategy that combined a prominent role for money with a broadly based assessment of the outlook for price developments and risks to price stability (cf. Hartmann and Smets 2018, p. 10). This is echoed in the omnipresence of the term "stability," which is featured in four word profiles (Issing, Hämäläinen, Duisenberg, Noyer). The quantitative reference value for the growth rate of a broad monetary aggregate, "M3," can be found in Noyer's word profile. Finally, some terms indicate idiosyncratic national influences, e.g., the apparent importance of "Hayek" in Issing's speeches and the term "finnish" in Hämäläinen's word profile.

Turning to the second generation of ECB Board members, grouped around the presidency of Jean-Claude Trichet, one detects significant semantic changes (Figure 5). Most importantly, the second generation had to deal with the onset of the "crisis" (Smaghi, Stark) that unfolded in the wake of the "Lehman" collapse (Smaghi) and brought financial "turmoil" (González-Páramo) and "risk" (Papademos, González-Páramo) to the global economy. In such troubled times, less time was spent discussing "stability" of prices (cf. Section 5 below), but the term still appears in three word profiles (Trichet, Stark, Papademos). Another major challenge was the "SEPA" initiative, which was frequently mentioned by Jean-Claude Trichet and particularly Gertrude Tumpel-Gugerell. Interestingly, the word profile of Trichet also captures his inclination to integrate German or French sentences into his speeches whenever he visited one of these countries.[6]

Finally, Figure 6 displays the highest tf-idf words for Mario Draghi's term as ECB president, which ended—together with the

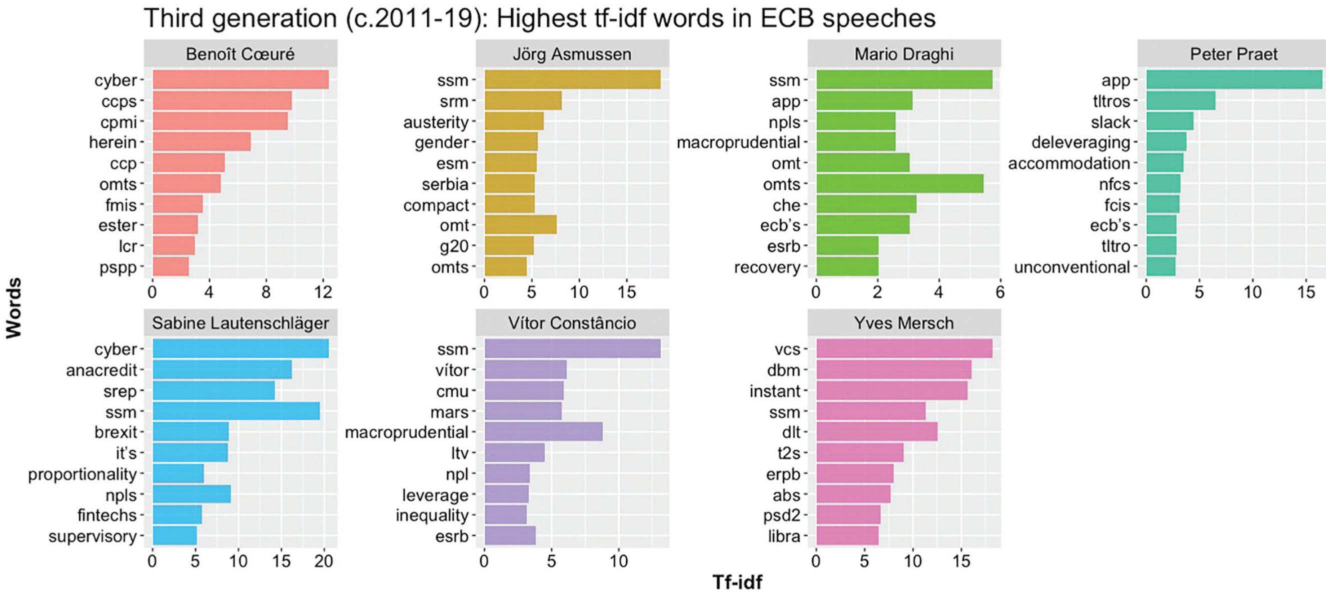
[6]When preparing the corpus, all English, German, and French stop words were removed via standard stop-word lists. The presence of German and French words within the highest ranked tf-idf words thus indicates that Trichet's speeches included not only simple terms but also whole sentences in foreign languages.

Figure 5. The 10 Highest tf-idf Words for Each Speaker in the Second Generation of ECB Executive Board Members



Source: ECB corpus; see description in the main text.
Note: This is based on calculating each term's tf-idf, which equals the frequency of a term adjusted for how rarely it is used. To enable better readability, the very low tf-idf values were scaled by a factor of 10,000. Of course, this does not change their relative size and therefore the message of this figure.

Figure 6. The 10 Highest tf-idf Words for Each Speaker in the Third Generation of ECB Executive Board Members



Source: ECB corpus; see description in the main text.
Note: This is based on calculating each term's tf-idf, which equals the frequency of a term adjusted for how rarely it is used. To enable better readability, the very low tf-idf values were scaled by a factor of 10,000. Of course, this does not change their relative size and therefore the message of this figure.

observation period of this corpus—in October 2019. The figure is characterized by numerous abbreviations related to finance and banking such as "SSM" (Single Supervisory Mechanism), "CCP" (central counterparty clearing house), or "ABS" (asset-backed security). Together with other technical terms like "macroprudential," they belong to the large group of high tf-idf words that are used by several speakers alike and reflect the analyses and solutions that the ECB proposed in the face of the Great Recession. This also indicates that most speeches refer to the same underlying discourses or deliver the same official message. Nevertheless, there are a few specialized terms that can be linked to individual speakers, such as "schooling" (Papademos), "Brexit" (Lautenschläger), "Libra" (Mersch), and "gender" (Asmussen). This in turn suggests a certain division of labor among Board members.

In sum, explanatory analysis of the ECB corpus via descriptive statistics and text mining methods suggests a decisive break in the semantic message of ECB speeches between the pre- and the post-crisis period. Following the outbreak of the Great Recession, the number of ECB speeches increased significantly, their net sentiment dropped from a generally positive to a negative tone, and their semantic content changed considerably (as measured by word correlations and td-idf). In the next section, the associated change in speech content will be traced more precisely via topic modeling.

3. Topic Modeling: Capturing Content and Dynamics

This section estimates a specific type of probabilistic topic model known as a structural topic model (STM).[7] Generally, topic models are algorithms for discovering the main themes that pervade a large collection of texts (Blei 2012). Without any prior categorization, topics emerge from the analysis of semantic data as captured in speeches and the model then organizes the corpus according to the discovered themes. These models are generative models of word counts, with a topic being defined as a mixture of words, with each word having a probability of belonging to a topic (cf. Silge and Robinson 2017). Analogously, a speech is understood here as a mixture of topics. The

[7]For an overview, see http://www.structuraltopicmodel.com (accessed December 2, 2020).

key innovation of STM is that it allows document-related information to be incorporated into the topic model. In the case of the ECB corpus, metadata corresponds to the speaker's name and the year in which the speech was given. The following analysis traces the effect of these metadata on topical prevalence, i.e., the frequency with which a topic is discussed. STMs have been applied to international newspapers (Roberts, Stewart, and Airoldi 2016), online class forums (Reich et al. 2015), and religious texts (Lucas et al. 2015).

The usual pre-processing steps are performed, including the removal of stop words (uninformative words like "the"), numbers, and punctuation. In addition, all words with less than three characters are removed, i.e., mostly abbreviations. Next, a threshold needs to be defined, which corresponds to the minimum number of speeches in which a word needs to appear in order for the word to be kept within the vocabulary. Here, a threshold of 2 is selected, meaning that a term has to be mentioned at least twice in order to be kept within the corpus. Following these pre-processing steps, the final corpus consists of 1,989 speeches, 19,244 terms, and 1,423,280 tokens.

Topical prevalence is modeled as a formula consisting of relevant "covariates." Since the ECB speeches' content varies according to speaker and phase of the crisis, it is intuitive to allow topic prevalence to vary with these metadata. Consequently, the frequency with which a topic is discussed (*prevalence*) is defined as a function of the *speaker* variable, indicating the speaker's name, and the variable *year*, which is an integer measure of years running from 1997 to 2019.[8] Based on this formula, a 10-topic model is estimated.[9]

Why estimate precisely 10 topics? STM requires a fixed user-specified number of topics, but there is not a "right" answer to the number of topics that is appropriate for a given corpus (cf. Grimmer and Stewart 2013). Assuming too few topics results in distinct issues being aggregated, whereas too many topics results in several unstable clusters referring to similar issues. While some statistical metrics for calculating the optimal number of topics do exist (e.g.,

[8]The variables are entered additively, and the year variable is allowed to have a nonlinear relationship in the estimation stage.

[9]Using *spectral initialization*, which means that independent of the seed that is set, the same results will be generated.

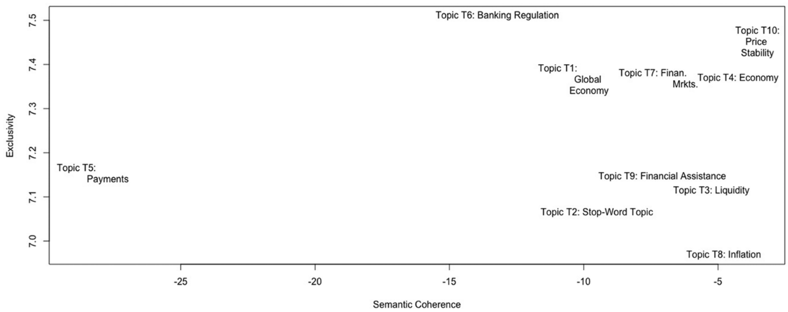
Cao et al. 2009), these measures only deliver the optimal number in a technical sense, while the true optimal number "depends on the research question" (Wehrheim 2019, p. 113, footnote 63). In a recent paper, ECB researchers apply a word-clustering approach (similar, but not equal, to STM) to a corpus of ECB speeches and estimate 50 topics, which they then manually group around 10 more general themes (Hartmann and Smets 2018). While their goal is to identify very specific topics in order to provide a detailed chronological history on the occasion of the ECB's 20th anniversary, this paper rather aims to detect communicative shifts in the ECB's general priorities. It is therefore justifiable to estimate 10 topics (a number that is also in line with the 10 general themes described by these ECB researchers) in order to understand the broader issues that the ECB was concerned with over the last 20 years.[10]

As a robustness check, one can measure the topic quality of the estimated topics through a combination of their semantic coherence and exclusivity. Semantic coherence is maximized when the most probable words in a given topic frequently co-occur together (cf. Mimno et al. 2011), whereas exclusivity of words to topics is included to ensure that high semantic coherence is not the result of a few topics being dominated by very common words (cf. Roberts et al. 2014). Figure 7 plots the semantic coherence and exclusivity scores for the 10 estimated topics. The results show that the selected model features desirable properties in both dimensions since the average scores of most topics tend to cluster towards the figure's upper right side.[11]

[10]Experimenting with other topic numbers confirms that selecting 10 topics is the best choice to ensure that the resulting topics are coherent and can be compared to the main historical lessons outlined by Eichengreen (2015).

[11]Given the scaling of the figure, it appears that topics 5 (payments) and 8 (inflation) could be statistical outliers that might bias the analysis. However, this impression is deceptive and is based on the fact that the *stm* package aligns the scaling of the axes for semantic coherence and exclusivity with the estimated values of the topics and not with the usual range of values. For example, if the exclusivity axis were to start at 0 instead of 7.0, T5 would be much further along the upper right ideal point. The same is true for semantic coherence, which stops at the left end of the axis at about –25 but can easily reach –100 in many STM applications. A comparison of the topics estimated here with the semantic coherence and exclusivity values of the topics estimated by Silge (2018) shows that all values are robust and should not be considered as outliers.

Figure 7. Topic Quality Measures for Each of the 10 Estimated Topics



Source: 10-topic STM, with M = 8 (M equals the number of words to use in semantic coherence and exclusivity calculations, since for computational reasons not all words can be used. For a discussion of M, see the foundational paper by Mimno et al. (2011), who mention a range of M = 5–20. The default in the R *stm* package is 10. Slightly changing M within this range (e.g., to M = 10) does not change the trends or general results of Figure 7. M = 8 was chosen for the pragmatic reason that it enabled plotting all topic labels without overlaps). For the estimation procedure, see description in the main text.
Note: Semantic coherence is maximized when the most probable words in a given topic frequently co-occur together, whereas exclusivity of words to topics is included to ensure that high semantic coherence is not the result of a few topics being dominated by very common words. For the complete labels, see Table 2.

In the context of STM, a topic can be understood as probability distributions over words, meaning that the estimated model returns several lists of words that have been identified computationally as having a high probability of occurring together. To interpret the computational output, researchers thus look at the words associated with each topic and manually attach a meaningful label. For instance, Küsters, Volkind, and Wagner (2019, p. 245) apply topic modeling to two recent Oxford handbooks on legal history, resulting in a list that consists of words such as "genocide," "nazi," "jewish," "criminal," and "tribunal," which suggests that the topic encompasses the discourse on "National Socialism and Law" that is present in many handbook articles. If a topic lacks a straightforward interpretation, it is helpful to read the documents that possess a large share of this topic in order to get a better sense for the appropriate label.

Table 2 gives four different types of word profiles, including the standard output of a topic model, i.e., the highest-probability words based on the probabilities that each word is generated from each topic. Three additional metrics are included. FREX indicates words that are frequent *and* exclusive to each topic (Airoldi and Bischof 2016). "Lift" weights words by dividing by their frequency in other topics, thereby prioritizing words that appear less frequently in other topics (Taddy 2013). Similar to lift, "score" divides the log frequency of the word in the topic by the log frequency of the word in other topics.[12] By combining various word profiles, it is possible to label the estimated topics much more precisely compared to the standard procedure in the literature that relies only on the highest-probability words. In particular, these word profiles help to identify 10 distinctive topics (Table 2).[13]

Topic 1 deals with "globalization" in general and "China," the "US," and "OECD" "countries" in particular. With terms like "productivity," "competitiveness," and "reforms," the emphasis is on domestic structural reforms whose necessity arises from the pressure of this *Global Economy* (T1). In most topic modeling exercises, there are a few topics that identify linguistical patterns lacking any kind of useful meaning and that can be safely ignored for the remainder of the analysis (cf. Wehrheim 2019, p. 90). The next topic, T2, represents such a topic because it acts like a corpus-specific *stop-word* list capturing many uninformative words that appear frequently in ECB speeches (e.g., the speaker's name, which is listed at the beginning of each speech) but were not captured by the general stop-word list implemented when estimating the STM.[14] However, this residual topic does not pose any problems since it constitutes only a minor share of the 10 estimated topics and does not exhibit any significant trends, which implies that it is not distorting the *relative* proportions of the other topics (cf. Figure 8 below).

Turning to the next topic, one encounters the *Liquidity Measures* (T3) that were enacted by the central banks as a reaction to the

[12]See https://cran.r-project.org/package=lda (accessed June 19, 2020).

[13]The manually attached labels are given in italics, whereas the key terms from the word profiles are marked via single quotation marks.

[14]This is known as the "boilerplate" problem (cf. Boyd-Graber, Mimno, and Newman 2015, p. 228). For the descriptive statistics (such as the tf-idf word profiles) provided in Section 2, however, the speakers' names were removed.

Table 2. A Topic Model with 10 Topics, 1,989 Documents, and a 19,244-Word Dictionary

Topic	Label	Metric	Word Profile
Topic 1	Global Economy	Highest Prob.	euro, growth, area, countries, economic, labor, global
		FREX	productivity, globalization, labor, china, oecd, workers, imports
		Lift	us, americans, catch, catching, comparisons, competitiveness, education
		Score	labor, productivity, wage, euro, inflation, reforms, unemployment
Topic 2	Stop-Word Topic	Highest Prob.	banks, one, even, many, just, time, bank
		FREX	bini, smaghi, lautenshläger, don't, thing, sabine, lorenzo
		Lift	even, ballot, bonaparte, button, cake, catalonia, cheated
		Score	lautenschläger, sabine, peseta, bini, smaghi, vice-chair, people
Topic 3	Liquidity Measures	Highest Prob.	financial, crisis, liquidity, banks, market, central, risk
		FREX	omts, turmoil, non-standard, lehman, tensions, allotment, exit
		Lift	appreciation, enhanced, default, deleveraging, emergency, enhanced, fault
		Score	crisis, liquidity, non-standard, omts, financial, operations, funding
Topic 4	General State of Economy	Highest Prob.	area, euro, inflation, growth, rates, policy, monetary
		FREX	outlook, recovery, quarter, oil, subdued, purchases, sustained
		Lift	access, careful, hysteresis, lifting, abschließend, abschluss, accommodation
		Score	inflation, app, recovery, euro, rates, wage, slack
Topic 5	Payments System	Highest Prob.	payment, euro, payments, european, sepa, market, central
		FREX	sepa, cards, epc, debit, card, payments, payment
		Lift	debits, sdd, ages, bitcoin, card—present, ethical, mined
		Score	sepa, banknotes, epc, debit, cyber, cards, settlement
Topic 6	Banking Regulation	Highest Prob.	financial, banks, banking, risk, supervisory, supervision, system
		FREX	ccps, supervisory, macroprudential, supervisors, macro-prudential, supervision, esrb
		Lift	ensuring, existing, know, lead, marrying, micro-based, recovery
		Score	macro-prudential, esrb, ssm, ccps, macroprudential, supervisory, supervisors

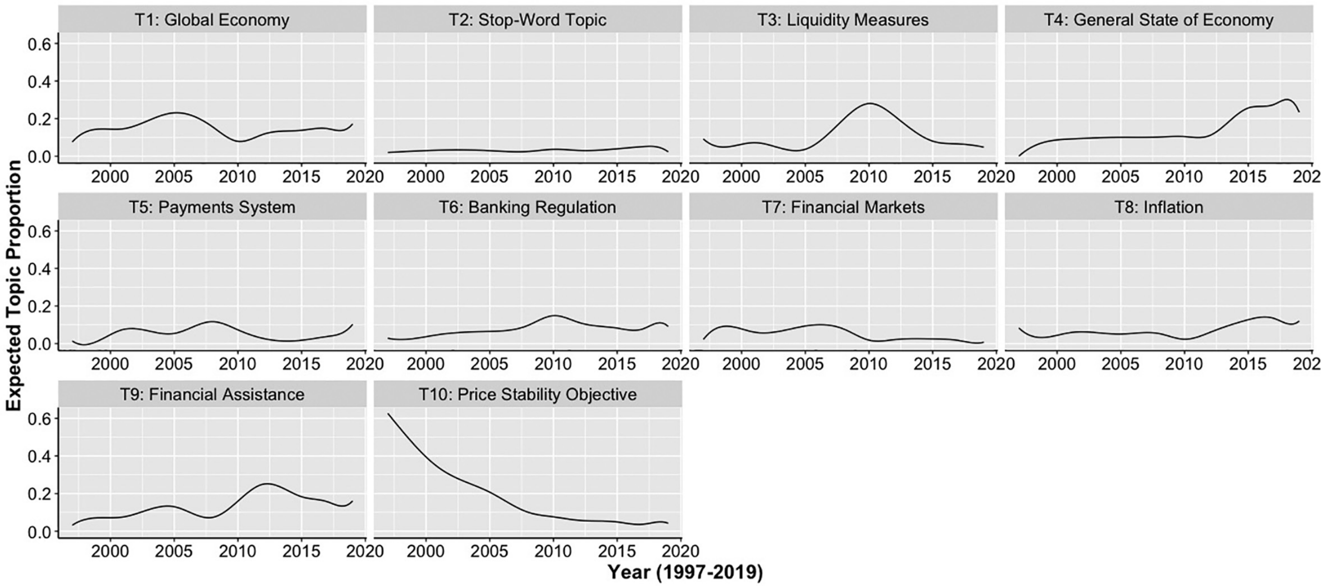
(*continued*)

Table 2. (Continued)

Topic	Label	Metric	Word Profile
Topic 7	Financial Markets	Highest Prob.	financial, market, markets, euro, integration, area, banking
		FREX	repo, mortgage, securitization, equity, diversification, bond, corporate
		Lift	buy-hold, cut, illusion, indicators, interstate, near-perfect, white
		Score	integration, financial, securities, bond, repo, euro, market
Topic 8	Inflation	Highest Prob.	policy, monetary, central, inflation, price, bank, rates
		FREX	zero, policy, equilibrium, monetary, phillips, bound, jackson
		Lift	predicting, reverse, commoditized, coordinating, cross-checking, empirical, flattening
		Score	inflation, policy, monetary, phillips, price, asset, central
Topic 9	Financial Assistance	Highest Prob.	european, euro, union, area, fiscal, economic, countries
		FREX	sovereignty, union, esm, legitimacy, emu, fiscal, political
		Lift	private, endogeneity, destin, oca, ever, m, secular
		Score	fiscal, union, integration, emu, pact, euro, european
Topic 10	Price Stability Objective	Highest Prob.	euro, monetary, policy, stability, price, area, central
		FREX	accession, escb, ecbs, erm, eurosystems, reference, treaty
		Lift	testing, training, bi-weekly, bones, boskin, bosnia-herzegovina, centripetal
		Score	accession, inflation, euro, monetary, erm, price, stability

Note: For each estimated topic, the table lists the seven most important words together with the manually given label. The seven words are ranked by statistical importance. The specified words given in this table are manually cleared word forms of the underlying tokens. Since no lemmatization procedure was applied when creating the corpus, the latter contains the actual word forms as used in the ECB speeches, including apostrophes and punctuation marks. These grammatical characters have been manually removed for the table to ensure better readability. For example, "-appreciation" was shortened to "appreciation". For the different metrics, see the explanations in the main text.

Figure 8. Graphical Display of Topic Prevalence



Source: 10-topic STM; for the estimation procedure, see description in the main text.
Note: Each topic's prevalence is plotted as a smooth function of year, holding speaker's influence at sample median, without confidence intervals.

market "turmoil" and "tension" following the "Lehman" collapse. This topic also includes "non-standard" measures such as the ECB's purchases in secondary, sovereign bond markets known as outright monetary transactions ("OMTs"). Words like "growth," "outlook," "recovery," "quarter," and "slack" suggest that topic 4 deals rather abstractly with the general state of the economy (T4), explaining trends in important macroeconomic indicators. This is underlined by the presence of some German words that suggest that this topic was mainly estimated on the basis of President Trichet's high-level speeches.[15] Topic 5 refers to the European payments system (T5) that was successively created through the ECB's "SEPA" payment-integration initiative and includes the diverse means of payments available to Europeans, ranging from "banknotes" and "coins" to "debit" "cards" and even "bitcoins."

The references to regulatory concepts such as "macroprudential" policy, the recently established European Systemic Risk Board ("ESRB"),[16] and new institutions for "supervision" of "banks" link topic 6 to the area of banking regulation (T6). Topic 7 refers to the integration of financial markets (T7) and their various products based on "securitization" of "mortgage," "diversification," or repurchase operations ("repo"). This is followed by a topic dedicated to the ECB's main activity, namely dealing with inflation (T8) through "monetary" "policy" and understanding its causes through academic analysis. The latter aspect is echoed in terms such as "Phillips" (curve), "empirical," and "equilibrium." Topic 9 deals with financial assistance that was granted to indebted euro-zone countries during the Great Recession, above all through the European Stability Mechanism ("ESM")—hence, the label financial assistance (T9). T9 also mentions the fiscal "pact," which enshrined the requirement to have a balanced budget rule in domestic legal orders, and touches upon issues of "legitimacy" and national "sovereignty" that were heatedly discussed in recipient countries. Finally, topic 10, labeled price stability objective (T10), refers to the "treaty" that describes the ECB's primary task to pursue "price" "stability." This topic is

[15] As mentioned and shown at an earlier stage, Trichet particularly liked to include German and French words in his speeches, not least to impress his audiences in these countries.

[16] The ESRB was established in 2010 to oversee the European Union's financial system and mitigate systemic risk.

largely estimated on the basis of early speeches, since it includes terms like "accession" and "testing."[17]

In addition to capturing the key content of ECB speeches over more than 20 years, the STM output also allows us to investigate the temporal dimension of these topics by plotting topic prevalence as a function of *year* (Figure 8). Taken together, the 10 topics mirror the evolution of the Great Recession quite remarkably. The presence of inflation concerns (T8), the ongoing focus on payments integration (T5), and the simultaneous disinterest in any types of liquidity measures (T3) before and throughout the 2007 ECB speeches reflect the then-prevailing narrative of Great Moderation. Following the Lehman bankruptcy in 2008, the shares of speeches discussing liquidity measures (T3) or banking reforms (T6) began to rise only gradually. Ultimately, speeches describing the ECB's fiscal assistance (T9) to states in financial difficulty peaked in 2012, when Greece received a second bailout package and the ESM was established as a permanent firewall for the euro zone (cf. Bistis 2016). Remarkably, inflation fear (T8) and insistence on price stability as primary objective (T10) formed an integral part of ECB speeches even in the most dramatic moments. Still, their individual trajectories differ significantly: While T10 is steadily declining and cannot reach pre-crisis levels for the entire duration of the Great Recession, inflation concerns (T8) intuitively bottomed out in the depths of the crisis but recovered quickly thereafter, reaching an all-time high after 2015. Accompanied by relatively late proposals for banking regulation (T6) that only peaked in 2010, these topics also formed the intellectual background for the bailout negotiations during the acute phase of the euro-zone crisis. As part of the Troika, the ECB participated in these negotiations.

It is particularly interesting to compare the development of the liquidity measures topic (T3) with the topic describing the ECB's concerns regarding inflation (T8), since the optimal extent of central banks' accommodating monetary policy during the Great Recession is controversially discussed until this day (Baldwin and Wyplosz 2015, p. 510; Eichengreen 2015; Mody 2018, p. 225). Interestingly, the share of speeches discussing liquidity measures, including OMTs, peaked in 2010, which is two years before Draghi's well-known

[17] It thereby complements T8, which focuses rather on the practical tools to analyze inflationary processes and is focused on the later period.

"whatever it takes" remarks. At the same time, inflations concerns (T8) were at their all-time low. From 2010, however, the share of speeches discussing the inflation topic increased significantly, pointing towards a change in priorities that will be further investigated below when discussing the "historical lessons" prevalent at that time.

This polarity is not only due to the ECB's statute with its single priority of price stability but might also reflect more broadly the internal disagreements between German "hawks" and Southern "doves" within the Board (on this general "battle of ideas," see Brunnermeier, James, and Landau 2016), which eventually became public when the German Board member Jürgen Stark resigned unexpectedly. In his January 2012 farewell letter to ECB employees, he justified his disagreement with a lesson that he had supposedly gained from looking at the past: whenever in history a central bank had subordinated itself to budgetary policy, Stark argued in his letter, it had to make concessions in its actual task of keeping the monetary value stable (*Der Spiegel* 2012). The following two sections take a closer look at similar historical analogies in ECB speeches in order to investigate whether historical lessons played a role in ECB communication during the Great Recession.

4. Defining "Lessons from the Past"

In the aftermath of the Great Recession's outbreak, numerous observers used references to the Great Depression and the lessons that might be learned (e.g., Eichengreen and O'Rourke 2010; Eichengreen 2016), including leading macroeconomists, central bankers, and economic historians (Hansen 2019, p. 169). Did historical analogies also play a role in ECB communication during this period? Research shows that ECB speeches constitute a "special category" within the ECB's regular communication because they sometimes contain elements of meta-communication—for instance, when Board members use the opportunity to reflect on their own approaches to monetary analysis (Noordegraaf-Eelens 2010, pp. 52f.). The existence of such elements of meta-communication means that one would expect to find references to "historical lessons" if they played a meaningful role within the ECB's decisionmaking or communication strategy during the crisis. In order to determine whether such historical analogies formed a part in the semantic shift of ECB speeches determined above, one first needs an analytical benchmark that allows to compare them with the estimated topics.

Such a benchmark can be derived from Eichengreen's monograph *Hall of Mirrors* that so far presents the most concise analysis of the various usages of the past by both politicians and central bankers during the Great Recession. Throughout the book, Eichengreen (2015, p. 1) emphasizes "how conventional wisdom about the [1929 crisis], what is referred to as 'the lessons of the Great Depression', shaped the response to the events of 2008-09." The narrative structure of these lessons evolves around some historical experiences but marginalizes others. This is crucial because "what is not told is not remembered, and what is not remembered cannot be taken into account in decision making" (Hansen 2015, p. 559). This perspective reflects the audience that Eichengreen addresses with his book. *Hall of Mirrors* is a book intended to be read by policy participants and therefore necessarily offers "less a history of crisis than a handbook," whose purpose "is to learn lessons, indeed to learn lessons about learning lessons" (Tooze 2015, p. 140).

A careful close reading of *Hall of Mirrors* enables the reader to identify seven distinctive lessons from the past that can be grouped around two phases of the crisis: lessons that inspired the immediate monetary and fiscal reactions when the crisis erupted and spread from the United States to Europe (2007–09); and lessons that shaped the later handling of the sovereign debt crisis in Europe (2010–15). All references to historical analogies that were mentioned multiple times by Eichengreen are summarized in Table 3, which lists the respective event and date, the lesson Eichengreen stated was learned, page references, and if Eichengreen is indicating whether the lesson was used by the ECB. These seven *lessons* (L1–L7), briefly described in the following, provide the analytical benchmark for the subsequent analysis of ECB speeches and therefore have to be kept conceptually apart from the *topics* in ECB speeches that were estimated through the STM.[18]

[18]Thus, whenever the term *topics* is used, I refer to the content of ECB speeches as approximated through the STM, whereas usage of the term *lessons* indicates that the argument refers to one of the episodes described by Eichengreen.

Table 3. Summary of Eichengreen's Key "Lessons from the Past" that Influenced Policymakers during the Great Recession

No.	Label	Description	Key Words	Protagonist	Pages in Eichengreen
First Phase: Global Financial Crisis (2007–09)					
L1	Liquidity	Friedman and Schwartz explain the Great Depression with the Federal Reserve's failure to act as the lender of last resort. Policymakers concluded that the central bank should flood the market with liquidity if a bubble bursts.	bubble, liquidity, macroprudential policy, accommodative stance, lender of last resort, 1929, 1930	Fed, ECB (slower)	63, 119, 176f., 186, 265, 269f., 282, 286f., 305
L2	Preoccupation with Banks	The 1930s crisis centered on the banking system. Influenced by that history, central bankers now looked to the banking system, while many of the most treacherous problems were in the shadow banking system.	(shadow) banking system, securitized mortgages, asset-backed commercial paper, 1930s	Fed, ECB	190f., 381
L3	Fiscal Stimulus	Fiscal policy during the Great Depression made only a limited contribution to recovery because the fiscal initiatives were too small. Obama's $787 billion fiscal stimulus was designed to avoid this mistake. Similarly, the G-20 arranged for expansionary policies.	fiscal stimulus, Obama, G20, private spending, New Deal, 1930s	U.S. government, G-20	297, 330f.
L4	Internat. Cooperation	Another lesson referred to the destruction that could be wrought by inadequate international cooperation. This inspired the effort in 2008–09 to coordinate monetary and fiscal policies and to shun protectionist measures.	protectionism, coordination, cooperation, World Economic Conference, Smoot-Hawley	Fed, ECB, IBS, politicians	122, 186, 236, 340f., 384

(*continued*)

Table 3. (Continued)

No.	Label	Description	Key Words	Protagonist	Pages in Eichengreen
		Second Phase: Euro-Zone Crisis (2010–15)			
L5	Fear of Inflation	Based on memories of the 1923 hyperinflation, Germany's fear of inflation translated into European policy. This meant that monetary policy was inadequately supportive of the economy.	hyperinflation, 1929, 1970s, headline inflation, price stability	Fed, ECB, Bundesbank	8, 40, 59f., 190, 254, 283, 303f., 338f., 383
L6	Austerity	The out-of-control budgets of Weimar, associations with Hitler's rearmament, and lack of Keynesian thought left German economists skeptical of deficit spending. This initiated a premature shift to austerity throughout Europe.	deficit spending, austerity, contract, competition	German government, ECB, Bundesbank	9f., 342, 352
L7	Regulatory Reforms	From historical experience, policymakers should have known that the flawed policies that allowed the crisis to develop in the first place should be fixed through comprehensive reforms put in place before the sense of urgency has passed. However, reform attempts came too late and were therefore insufficient.	regulation, reform, Dodd-Frank Act, too-big-to-fail, Volcker Rule, systemically important	Policymakers	247, 378, 386

Source: Eichengreen (2015).
Note: This list is not given by Eichengreen himself but was manually constructed based on close reading of his book.

The narrative constructed by Friedman and Schwartz (1963) in their *Monetary History of the United States* is probably the best-known lesson from the past. They associated the Great Depression with the Federal Reserve's failure to act as the lender of last resort and to provide liquidity to financial markets during the early 1930s banking crises. According to Eichengreen, central banks both in the United States and in Europe acted in line with this lesson by quickly *flooding the market with liquidity* (L1). When interbank rates rose above the ECB's target following the BNP Paribas announcement, the ECB offered to provide unlimited amounts of liquidity: "Even in Frankfurt they had evidently read Friedman and Schwartz" (Eichengreen 2015, p. 177).

However, unlike the Great Depression, the 2007 crisis did not center on commercial banks, but on the shadow banking system of hedge funds, money market mutual funds, and commercial paper issuers. Standard central bank interventions were thus less effective. According to Eichengreen, the central banks' erroneous *targeting of the banking sector* (L2) was based on historical experiences. As he notes regarding the Fed: "The 1930s crisis centred on the banking system. Influenced by that history, it was to the banking system that the Fed now looked" (Eichengreen 2015, p. 190f.).

Besides central banks' reactions, active fiscal policy was needed to counter the crisis. For instance, the Obama administration designed a $787 billion *fiscal stimulus bill* (L3) that, according to Eichengreen, was informed by the impression that both the Hoover and Roosevelt administrations had done too little to offset the decline in private spending during the 1930s. Christina Romer, Obama's economic advisor, had argued that during the Great Depression, fiscal policy had been of little consequence because fiscal stimuli were too small (Romer 1992). Now, politicians both in the United States and in Europe aimed to "prevent the repetition of this mistake" (Eichengreen 2015, p. 297).

During the Great Depression, central banks had been slow to coordinate their actions to enable the functioning of the gold standard. Eichengreen argues that this historic lesson inspired *international cooperation* in 2008–09 (L4). Major central banks coordinated interest rate cuts in October 2008 and set up foreign exchange swap lines, while governments coordinated financial bailouts and fiscal stimuli (Duca 2017, p. 59). Eichengreen (2015, p. 122) argues that the "ritual invocation" of the Smoot-Hawley tariff helped policymakers to resist protectionism and that British Prime Minister Gordon Brown reminded G-20 leaders how the failure of the 1933 World Economic Conference "had foreshadowed all the other terrible events of that decade and the one to follow" (Eichengreen 2015, p. 340).

According to Eichengreen's account, the emphasis of policymakers shifted after this first phase of the crisis. From 2010 onwards, new lessons about the danger of inflation and the necessity of balanced budgets prevailed, especially in Europe, while banking reforms came too late: "This shift occurred despite the fact that the recovery continued to disappoint," Eichengreen complains. "Rather than avoiding the mistakes of the 1930s, policy makers almost seemed intent on repeating them" (Eichengreen 2015, p. 284). If Eichengreen's hypothesis is true, one should therefore observe a change in argumentation over time, with lessons L1–L4 becoming less prominent and lessons L5–L7 increasing their respective proportions in ECB speeches.

Germany's *fear of inflation* (L5), based on memories of the 1923 hyperinflation, translated into European policy because of the ECB's Bundesbank-like structure and "the desire of its French president, Jean-Claude Trichet, to demonstrate that he was as dedicated an inflation fighter as any German" (Eichengreen 2015, p. 8). According to Eichengreen (2015, p. 254), the German public was "traumatized by inflation" and those fears of inflation "informed and inhibited policy in other countries." Consequently, monetary policy was not supportive enough.

Similarly, the idea that fiscal stimuli could facilitate the recovery was dismissed by the German public, who associated deficit spending with historical episodes of out-of-control budgets and Hitler's rearmament, as well as with more recent experiences of fiscal profligacy and high inflation in Southern European countries in the 1970s and 1980s. Keynesian theory had never gained traction in Germany (Allen 1989). German economists therefore argued that the government should focus on strengthening contract enforcement and fostering competition. Overall, this mix of peculiar German experiences is said to have encouraged an *early shift to austerity* (L6).

Finally, policymakers were aware that the flawed policies and institutional structures that had enabled the crisis needed to be fixed through *comprehensive reforms* (L7). Banks are now subject to higher capital and liquidity requirements. However, historical experience suggests that to be effective, such reforms have to be put in place "before the sense of urgency has passed" (Eichengreen 2015, p. 378). According to Eichengreen (2015, p. 386), the fact that "another Great Depression was avoided weakened the argument for more radical changes." He argues that policymakers prioritized recovery over reform during the first phase, implying that efforts to develop banking reforms came too late.

Eichengreen's narrative provides anecdotal evidence but no systematic evaluation of how exactly these historical lessons have been applied in decisionmaking. A typical example for the type of evidence given by Eichengreen (2015, p. 170) is a remark addressed by Bernanke to Professor Friedman in 2002: "Regarding the Great Depression. You're right, we did it. We're very sorry. But thanks to you, we won't do it again." In his book review, Hansen (2015, p. 562) critically notes that "this case is the only explicit example where Eichengreen substantiates empirically how decision makers understood the crisis through the lens or frame of the 1930s." Consequently, the goal of the remainder of this paper is to empirically test Eichengreen's hypothesis about the influence of historical lessons as defined above (L1–L7), using the corpus of ECB speeches as a case study.

5. Tracing "Lessons from the Past"

Proceeding in three stages, this final section analyzes the usage of historical analogies in ECB communication as captured in the corpus of ECB speeches. First, the impact of Eichengreen's seven historical lessons can be compared with the semantic shift in ECB speeches as measured by the STM with its estimated topics. Next, it is possible to search the corpus directly for both key terms and key dates that could refer to these lessons. Finally, a qualitative analysis of historical analogies based on all ECB speeches given between 2007 and 2015 is conducted. Although all three approaches for capturing historical lessons indicate that the latter played an increased role in ECB communication at the height of the Great Recession (in line with net sentiment shown above), the qualitative analysis suggests that this role was rather marginal and less substantive than suggested by economic historians.

To begin with, one can compare Eichengreen's historical lessons with the topics estimated by the STM. In cases where one (or several) historical lessons are represented by an estimated topic, one receives an upper-bound estimate for the prevalence of the respective lesson in the ECB's communication. Note that this is only a first approximation, given that the estimated topics span more than 20 years and are therefore much broader than the very specific lessons described above. Although these proportions are thus upward-biased estimates, they still give valuable indications of the lessons' potential occurrence and their significance in ECB communication *relative* to each other.

First of all, one needs to clarify which topics could approximate the different historical lessons. Most importantly, one could draw a link between ECB Board members' discussions about inflation (T8) with the historic fear of (hyper)inflation (L5), not least because the politically neutral ECB was structurally modeled on the basis of the German Bundesbank with its sole emphasis on price stability (e.g., Bibow 2013; for a discussion, see Feld, Köhler, and Nientiedt 2015). As Berghahn and Young (2013, p. 776) put it, "Both the Maastricht Agreement and the accompanying Stability and Growth Treaty bear the handwriting of the Germans." In addition, it is plausible to assume that there is a certain relationship between discussions of the need for more competitiveness and productivity (T1) and Northern Europeans' demands for structural reforms (L6), between the ECB's liquidity measures (T3) and the Friedman and Schwartz story (L1), and between the banking regulation topic (T6) and the allegedly history-driven focus on banks (L2) as well as the need to regulate them quickly (L7).

By contrast, the estimated topics do not refer to the need for fiscal stimulus packages (L3) and international cooperation (L4). The absence of L3 supports the hypothesis that the prevailing discourse on "austerity" as a solution for the sovereign debt crisis excluded the issue of fiscal stimulus. Still, it could also reflect the fact that fiscal stimulus packages are the responsibility of national governments, and not the ECB. The absence of L4 in turn could be partly explained by the fact that cooperation between euro-area countries had been already institutionalized under the Stability and Growth Pact. Assuming that there is a link between some of the historical *lessons* and ECB *topics* in the way outlined above, are the dynamics of these topics in line with Eichengreen's narrative?

To begin with, European central bankers' sensitivity to inflation (L5) is captured by the continued presence of the inflation topic (T8), accompanied by the topic describing the price stability objective (T10), even in the most dramatic months. To a certain extent, this simply reflects the fact that price stability is the explicit mandate of the ECB, so one would naturally expect that it is always mentioned in ECB speeches. Particularly from 2012 onwards, however, discussions about inflation (T8) assumed ever larger proportions in ECB speeches, supporting Eichengreen's (2015, p. 304) notion that the "mandate to pursue low inflation . . . continued to guide and constrain policy." According to Eichengreen (2015, p. 284), the analogy with the Great Depression "was foremost in the minds of policy makers" during "a brief period in 2008-09," but afterwards, "the emphasis shifted" towards balanced budgets. His timing of this premature shift to austerity (L6) is confirmed by the STM, which records a steady increase of discussions about competitiveness, productivity, and structural reforms (T1) from 2010 onwards.[19]

Similarly, the central banks' "readiness to provide not just liquidity but unlimited amounts of liquidity" (Eichengreen 2015, pp. 176f.) that was informed by economic history (L1) is mirrored by the liquidity topic (T3), which rises rapidly between 2007 and 2009 and peaks in 2010. Thereafter, T3 declines in line with the ECB's first "phasing-out." The extent to which liquidity measures were discussed in ECB speeches continued to decline in later years. This is again in line with Eichengreen's argument that in the European context, the analogy with the Great Depression was particularly influential in the first years of the crisis, but not afterwards. This is further supported by the trajectory of T9, which fits well with the argument for fiscal stimulus (L3) but reaches a low point in 2008 and only increases after the peak of the crisis, probably in tandem with the Greek bailout packages.

Eichengreen (2015, p. 381) also notes that central banks' policies were targeted at banks (L2) due to a "historically informed vision of the risks" and given T6's continued presence, this preoccupation with banks is visible in ECB speeches. However, given that

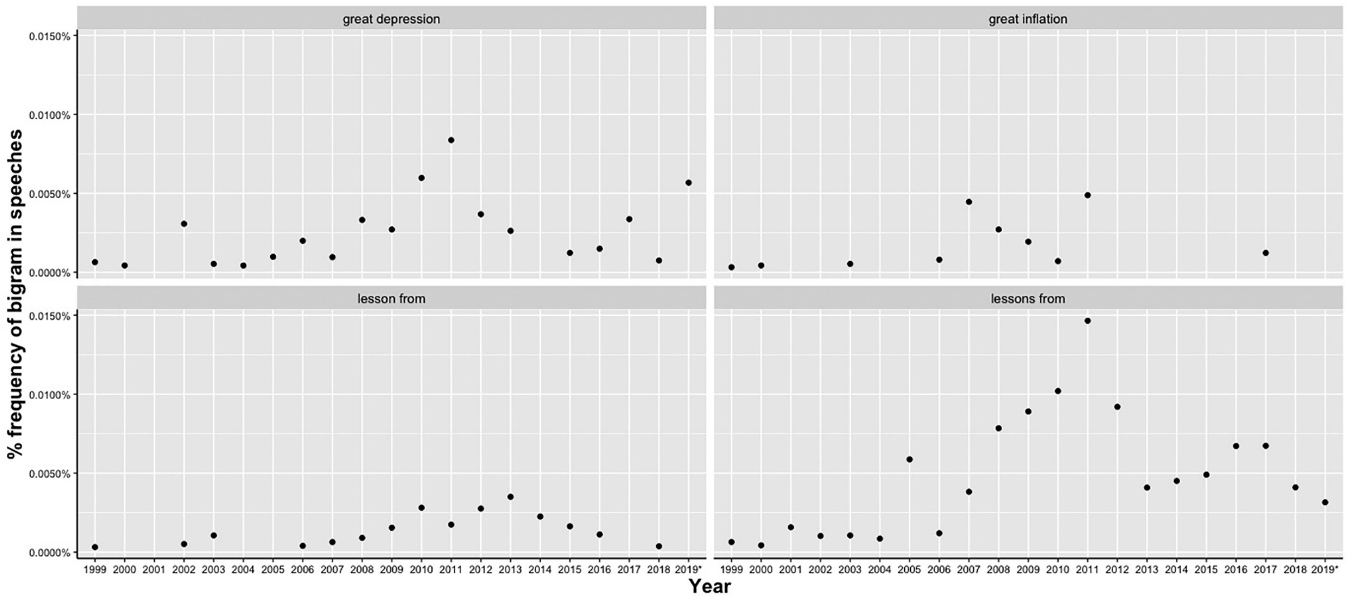
[19]Interestingly, T1 is also prominent before the crisis, but the main point for the argument put forward here is that it is recovering quickly from its low point in 2010.

the shadow banking system is significantly smaller and less relevant in Europe than in the United States (Shambaugh 2012, p. 162), this historical lesson of focusing on the banking system suits well the structural characteristics of the European financial system. Additionally, the evolution of T6, which contains proposals for banking reforms, supports Eichengreen's notion that banking reforms were initiated too late (L7), as T6's proportion is especially large from 2010 onwards but rather small when the financial crisis spread from the United States to Europe. Still, it should be noted that the characteristics of the EU legislation process make agreements on reforms of banking regulations complex and time-consuming (cf. Sum 2016).

Finally, although not related to Eichengreen's lessons, the payments topic (T5) closely follows the SEPA initiative's actual development, peaking in 2008 when SEPA pan-European payment instruments became operational and declining after SEPA payments had successfully replaced national payments in 2011. Overall, the estimated topics show that at the beginning of the crisis the focus was almost exclusively on monetary policy and, in particular, the provision of liquidity. Fiscal policy and banking reforms were postponed for the time being and when they were discussed again a few years later, after the crisis had bottomed out, the focus of the discussion had already shifted to the threat of inflation and austerity.

A more direct approach for identifying lessons from the past is to search the corpus for key terms such as "history," "lessons," or "past." However, manual search quickly makes clear that taken on their own, these multifunctional words are often unrelated to actual lessons from the past. For instance, the term "history" is frequently evoked at the beginning of a speech, when the respective ECB Board member briefly reviews the history of the location that forms the context for her or his speech. One gets a more precise picture by tokenizing the ECB corpus into consecutive sequences of words. When tracing the Great Depression analogy, it makes sense to examine pairs of two consecutive words, called "bigrams" (Figure 9). The resulting diagrams underline that there was indeed a sharp increase in references to the "Great Depression" in 2010 and 2011, and more generally to "lesson(s) from" the past. As a comparison, references to the "Great Inflation" in the wake of the 1970s oil-price shocks occurred less frequently, but even here we detect an increase in references at the height of the Great Recession. Taken together, in all

Figure 9. Relative Frequency of Key Bigrams Related to Lessons from the Past



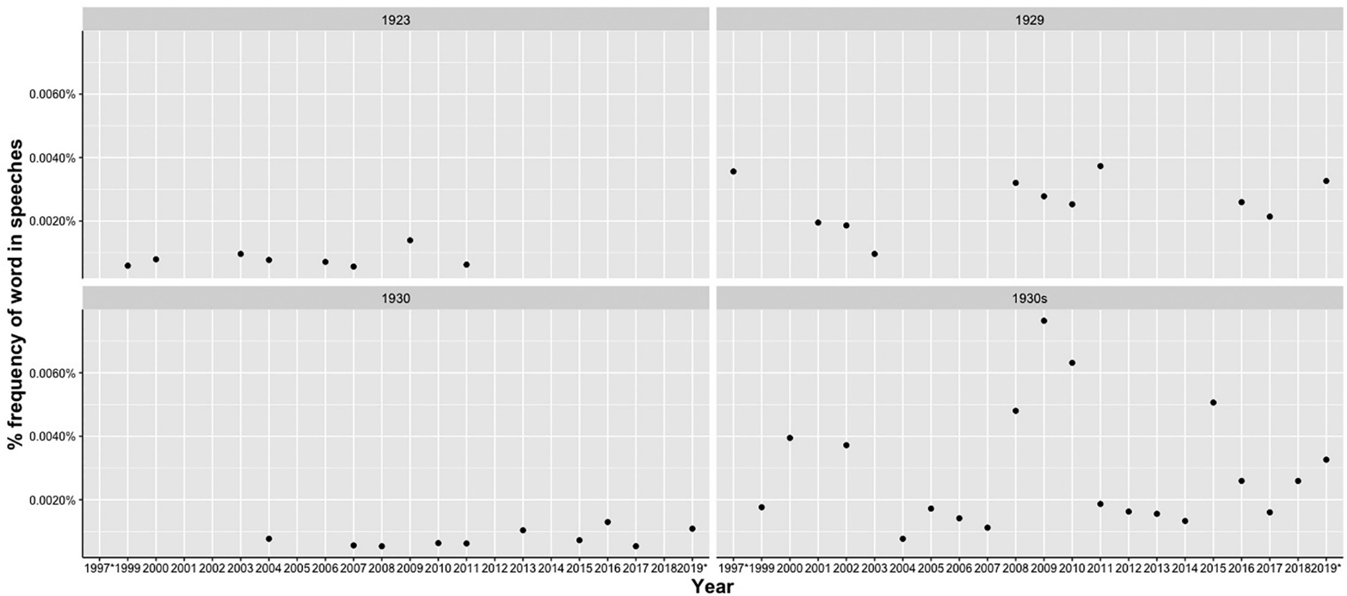
Source: ECB corpus; see description in the main text.
Note: Frequency is given as percentage of the respective bigram's occurrence in all words spoken in a given year. Since 2019 features only partial observations, it is not directly comparable and thus marked with an asterisk. While in principle it would be better to combine both bigrams "lesson from" and "lessons from" to a single value, this is technically not possible with this data set and the R packages on which the analysis is based. However, both curves show the same trend.

four panels of Figure 9, a strong increase in relative bigram frequencies can be seen in the second half of the observation period, i.e., during the Great Recession. These results are in line with the sentiment analysis presented earlier, and the hypothesis that historic lessons are especially prevalent in times of crises that can be captured through negative net sentiment.

In addition to bigrams, specific dates might be a precise proxy for tracing historical lessons. A good example is a 2008 speech given by Smaghi, who reflected on "what the errors of the past could teach us," asking particularly "what was done in earlier crises, in 1929, 1974–75, 1992–93 and in 2001–2002?" (Smaghi: May 15, 2008). Smaghi identified four distinctive lessons from the past. First, he emphasized the importance of price stability (L5) and demanded that any "rise in headline inflation must remain temporary." This supports Eichengreen's accusation that the ECB's "extraordinarily destructive" decision to raise its main policy rate by 25 basis points to 4.25 percent in July 2008 (two months after Smaghi's speech) was grounded in a mistaken focus on headline inflation, which in turn resulted from inflation aversion in Germany, where "the distinction between headline and core inflation was dismissed out of hand" (Eichengreen 2015, p. 339). Secondly, Smaghi referred to the "experience of Germany" to denounce potential Keynesian countermeasures to the crisis as "illusions," echoing German economists' skepticism regarding deficit spending (L6). Thirdly, he argued that the 1929 crisis showed that policymakers should not "put up protectionist barriers" in response to a financial crisis, and, echoing Eichengreen (2015, p. 122), invoked Smoot-Hawley as a negative example (L4). Finally, Smaghi noted that all support measures for distressed financial institutions should support "market liquidity" but not relieve investors from "solvency risks." This peculiar combination of the classic Friedman-Schwartz-liquidity lesson (L1) with moral hazard concerns could again signal the influence of German economists, who stressed the importance of liability and disciplining behavior throughout the crisis (Guiso, Herrera, and Morelli 2016, p. 111).

Smaghi's remarks suggest that searching the corpus for the dates of the 20th century's main economic crises and visualizing how their occurrence changed over time is an efficient strategy for capturing historical lessons within ECB speeches (Figure 10). In line with the

Figure 10. Relative Frequency of Key Dates Related to Lessons from the Interwar Period (hyperinflation and Great Depression)



Source: ECB corpus; see description in the main text.
Note: Frequency is given as percentage of the respective date's occurrence in all words spoken in a given year. Since 1997, 1998, and 2019 feature only partial observations, they are not directly comparable and thus marked with an asterisk.

sentiment analysis and the key bigrams shown earlier, the resulting figure reveals that Board members referred increasingly to "1929" and "1930s" during the Great Recession, with a potential peak between 2009 and 2011. Such bell-shaped patterns are typical phenomena in the field of narrative economics and have been found for the spread of intellectual innovations such as the IS-LM model, the multiplier-accelerator model, and the real business cycle model (Shiller 2017; also Hansson 2021). This implies that during a crisis, the narrative recourse to historical lessons follows the typical innovation cycle of adoption, peak, and decline. By contrast, recourses to the "1923" hyperinflation were less frequent and did not occur at all once the crisis dispersed, whereas references to "1930" as a single year increased only lately.

At this point, the higher prevalence of historical analogies during the Great Recession compared to previous years should be firmly established. Turning from the quantitative to the qualitative, the follow-up question is therefore which specific lessons were utilized during this time of crisis. To get an impression of this, a subset of the corpus covering all ECB speeches during the Great Recession (2007–15) is searched for references to the German hyperinflation ("hyperinflation," "1923") and for the dates commonly associated with the Great Depression ("1929," "1930," "1930s").[20] Within this subset, these five search terms can be found in 90 speeches (8.92 percent). The comparatively smaller number of speeches allows for a detailed close reading, on the basis of which each speech can be manually classified according to the specific historical lesson evoked by the speaker. In particular, it is determined if the speaker used the respective term only in a loose, comparative way (like "The world is hit by a severe crisis, the deepest since the beginning of the Great Depression in 1929") or if she or he outlined one of the historical lessons (L1–7) in more detail. Naturally, this procedure is more subjective than counting words or estimating a topic model, but it is

[20] In addition to the dates, the term "hyperinflation" is specifically searched for, since close reading of the ECB speeches shows that it is used almost exclusively with respect to the German hyperinflation of the interwar period. By contrast, references to the "Great Depression" usually referred to the historical episode only in a loose, general way that did not suggest the intentional utilization of a "historical lesson."

Table 4. Tracing Lessons from the Past in ECB Speeches between 2007 and 2015

Lesson	1923	1929	1930	1930s	Hyperinflation	SUM
Price Stability (L5)	1	0	0	5	7	13
Cooperation (L4)	0	1	2	8	0	11
Liquidity (L1)	0	5	0	5	0	10
Austerity (L6)	0	0	0	5	1	6
Regulation (L7)	0	2	0	4	0	6
Bank Focus (L2)	0	0	0	4	0	4
Fiscal Stimulus (L3)	0	0	0	0	0	0
No Lesson	3	6	2	25	4	40
Sum	4	14	4	56	12	90

Note: The results refer to a manual classification procedure, as described in the main text. The specific lessons L1–L7 are defined in Table 3. Each time a speech used a certain historical analogy only in a loose, comparative way (e.g., "The world is hit by a severe crisis, the deepest since the beginning of the Great Depression in 1929") without further elaboration, it was classified as "No lesson."

still likely to capture the *relative* importance of individual lessons. Typical excerpts from speeches classified in this way are given below.

Three findings emerge from this exercise (Table 4). First, almost half of the identified references are only rhetorical means that are unrelated to the usage of actual historical lessons, shrinking the latter's proportion in the subset of speeches to roughly 5 percent (overall corpus: 2.34 percent). It is therefore questionable if historical lessons constituted a significant pattern, given their quantitatively minor role.

Secondly, we can identify a division of labor with respect to the way that specific historic experiences are remembered. The German experience of a "hyperinflation" in "1923" is typically mentioned when the speaker aims to emphasize the economic and social importance of rigorous price stability, while "1929" immediately leads to associations of insufficient liquidity. By contrast, references to the "1930s" period in general can form the background to various, even conflicting, lessons, but their most frequent purpose is to illustrate the need for cooperation.

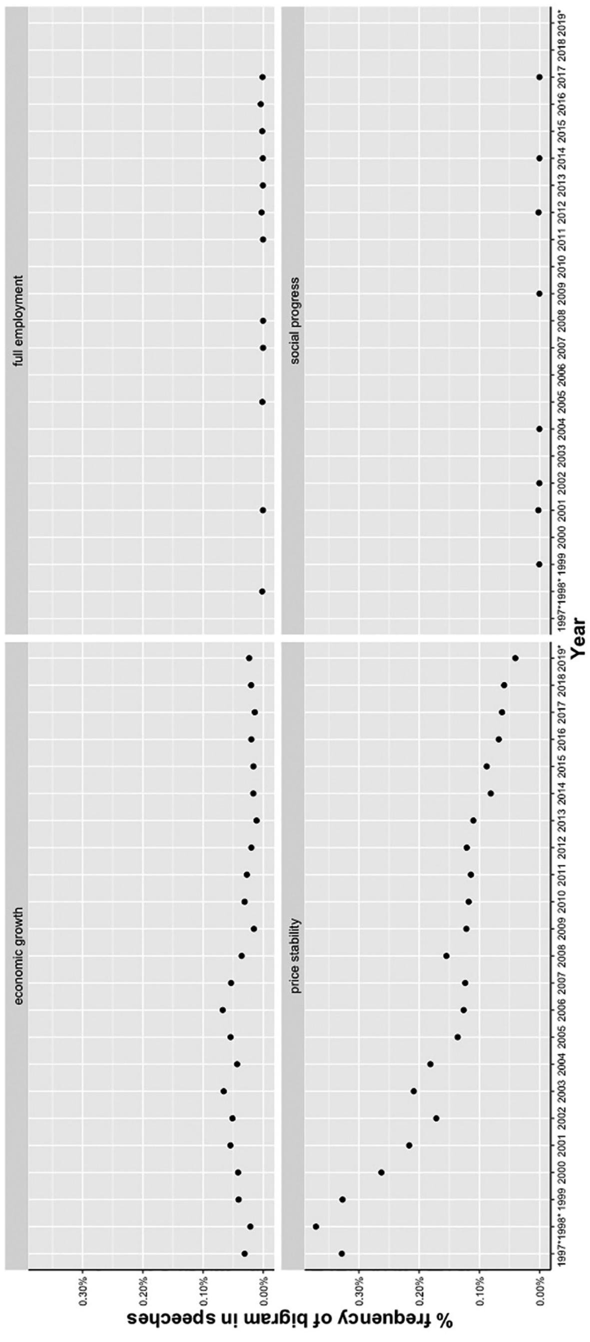
Thirdly, if we understand Eichengreen's seven lessons as a pool of lessons readily available when a speaker decides on the speech's content, the aggregate ranking of lessons as actually used reveals the Board members' preferences. Price stability, cooperation, and liquidity seem to have been their main priorities, and the respective lessons invoked in their favor recall Eichengreen's narrative. Speaking in Munich, Trichet recalled the German hyperinflation, which "has left deep scars in the collective memory of both Germany and Europe" and demonstrated "how painful deviations from price stability can be." According to Trichet, "these lessons of history were shared all over Europe" and with the creation of the ECB, Germany's stability culture had been fully "europeanized" (Trichet: July 13, 2009). ECB Board members regarded the post-WWI hyperinflations as one of the few "natural experiments" offered by economic history whose lessons were "deeply entrenched into the collective psyche of many European peoples" (Stark: June 11, 2008). Lessons about liquidity were likewise in line with Eichengreen's analysis in that they frequently mentioned Friedman and Schwartz. How to conduct monetary policy during a downturn had been "shown by Milton Friedman and Anna Schwartz already long ago" (Smaghi: November 25, 2008). Their "seminal analysis" had "taught" the central bankers that the Federal Reserve's failure to "provide enough liquidity to the financial system" had amplified the Great Depression: "This time we made sure we avoided a similar scenario" (Tumpel-Gugerell: May 3, 2011). Interestingly, Praet acknowledges that while Friedman and Schwartz's analysis provided "inspiration," it did not offer an "off-the-shelf recipe" since it only stated a "general rule without a detailed prescription" (Praet: November 26, 2012). This suggests that historical lessons provide a convenient analytical starting point in a crisis situation but are not sufficient to design the technical implementation of the necessary policies. Finally, it is remarkable that even in a non-U.S. context, lessons about cooperation included hortatory reminders of Smoot-Hawley (Smaghi: May 15, 2008), thereby giving credibility to Eichengreen's claim that its "ritual invocation" helped policymakers resist protectionism.

Next, lessons about austerity, regulation, and the role of banks form a second group of lessons that were occasionally mentioned. The moral hazard concerns expounded in favor of early austerity measures signal again a proximity to German priorities. While Stark (February 25, 2010) admitted that "discretionary government intervention has been key in forestalling a repeat of a 1930s-style depression," he criticised the "policy hyper-activism" of some countries and demanded a stability-oriented policy framework to ensure that fiscal authorities "withdraw stimulus to safeguard public solvency." The fact that several speeches referred to lessons about the banking sector and its potential regulation supports Eichengreen's lessons L2 and L7, but it should be noted that the ECB was nevertheless aware of the systemic risk arising from the shadow banking sector (Constâncio: February 13, 2015). Finally, just as the topics estimated by the STM, the identified historical lessons omit the positive role played by fiscal stimuli during times of recession (L3).

The observation that price stability has been the lesson most evoked by ECB Board members even aggregates this apparent contrast with the developments in the United States. Not least, this has institutional reasons, namely the fact that unlike the Fed with its dual mandate, the ECB's statute defined the responsibility for price-level stability as single priority. Still, once the primary objective is fulfilled, the ECB also supports the general economic policies in the European Union (Driffill and Rotondi 2004). These so-called secondary objectives include, for example, balanced economic growth, full employment, and social progress. One can trace the importance of these secondary objectives vis-à-vis the price stability goal by searching the ECB corpus for the corresponding bigrams (Figure 11). While price stability was and remains by far the most frequently cited objective in ECB speeches, one can identify a constant decline in the term's usage, both in relative and in absolute terms. Figure 11 reports only the relative frequency, i.e., how often the bigram was used in relation to the whole number of spoken words in a given year. While the term "price stability" was used more than 1,000 times in 1999, it has been used less than 250 times per year since 2014. The decline in absolute frequencies suggest that this trend cannot be explained with the increasing number and length of speeches.

This finding is also in line with the fact that the STM estimated a topic on the basis of price stability terms (T10) whose proportion in ECB speeches declined significant throughout the Great Recession. Despite the fact that ECB speeches continue to address the inflation topic (T8) in great proportion, the hypothesis put forward by Eichengreen and others that Germany's inflation aversion has biased ECB policy too much during the Great Recession is difficult to square with this decline in "price stability" references. For reasons of space, this interesting aspect cannot be discussed further, but it

Figure 11. Relative Frequency of Key Bigrams Related to Primary and Secondary Objectives of the ECB



Source: ECB corpus; see description in the main text.

Note: Frequency is given as percentage of the respective objective's occurrence in all words spoken in a given year. Since 1997, 1998, and 2019 feature only partial observations, they are not directly comparable and thus marked with an asterisk.

forms a worthwhile field for future research, not least in light of the ECB's recently concluded strategy review.

In sum, although most of Eichengreen's lessons can be substantiated with content from ECB speeches, this finding is, to a certain extent, qualified by the small proportion of speeches that actually describe these lessons. This ambiguity can be detected even in the case of price stability, an institutionally enshrined objective of the ECB that was historically informed by German interwar experiences: While the STM was able to show that there is a continued presence of the inflation and price stability topics in ECB speeches throughout the Great Recession, this has nevertheless been accompanied by a declining frequency with which the actual term is used.

6. Conclusion

This paper employed text mining methods such as structural topic modeling to examine all 2,135 speeches by ECB Executive Board members between February 1997 and October 2019. It thereby identified and analyzed the significant semantic change that occurred in ECB communication in the transition from the Great Moderation to the Great Recession. The methodology also allowed for a structured and empirical assessment of the hypothesis that central bankers increasingly referred to "lessons from the past" during the crisis. Three main findings arise from this analysis.

Firstly, explanatory analysis of the ECB corpus via descriptive statistics and text mining methods revealed a decisive break in ECB communication between the pre- and the post-crisis period: the number of ECB speeches increased significantly, their semantic content changed considerably, and their general tone became more negative. This was also substantiated through the STM that distilled the key 10 topics underlying ECB speeches and showed how their respective proportions changed particularly during the Great Recession.

Turning to the question of whether this semantic change was accompanied by an increased usage of lessons from the past, this paper found empirical evidence for some of Eichengreen's (2015) lessons that went beyond the occasional anecdote à la Bernanke. Frequency analysis of key bigrams and dates related to the Great

Depression confirmed that there was indeed an increase in historical analogies, particularly between 2009 and 2011. Interestingly, ECB speeches kept referring to the inflation topic (L5) throughout the Great Recession, while liquidity measures (L1) were only discussed briefly. The temporal dimension of this evidence, as measured by the STM, corresponds to Eichengreen's narrative and confirms a shift in policy priorities from 2010 onwards. This is also in line with the development of net sentiment, as measured for the ECB corpus, suggesting that sentiment analysis can help identify times of crises that are likely to lead to an increase in historical analogies.

Finally, the speeches that actually described these historical lessons in more detail, as opposed to merely including comparisons with the Great Depression as a rhetorical device, constituted only 5 percent of all speeches given between 2007 and 2015. While this still reflects an interesting and persistent rhetorical pattern, its marginal quantitative size qualifies the claim about a dominant, all-encompassing influence of historical lessons during the Great Recession.

By discussing the corpus of ECB speeches in detail and by introducing methods such as structural topic modeling that so far have been overlooked in the analysis of ECB communication, this paper contributes to the rapidly growing literature that aims to quantitatively investigate central bank communication through means of natural language processing. In doing so, the paper also advances an understanding of the ECB's communication process during the Great Recession by tracing and analyzing the historical analogies contained in ECB speeches. Future research could expand on these findings by clarifying how these historical analogies relate to macroeconomic parameters, to rhetorical legitimation strategies in front of different national audiences, or to investors' confidence. This would help to better understand the role of economic narratives (in the sense of Shiller 2017) in central bank communication (Hansson 2021). In particular, the findings presented in this paper raise the question of the extent to which complex and often ambiguous references to "lessons from the past" constitute, in a technical sense, "noise" in central bank communication that ultimately reduces the latter's predictability, effectiveness, but also general accessibility (Haldane and McMahon 2018).

References

Airoldi, E. M., and J. M. Bischof. 2016. "Improving and Evaluating Topic Models and Other Models of Text." *Journal of the American Statistical Association* 111 (516): 1381–1403.

Allen, C. 1989. "The Underdevelopment of Keynesianism in the Federal Republic of Germany." In *The Political Power of Economic Ideas*, ed. P. A. Hall, 263–90. Princeton, NJ: Princeton University Press.

Baldwin, R. E., and C. Wyplosz. 2015. *The Economics of European Integration.* London: McGraw Hill.

Berghahn, V., and B. Young. 2013. "Reflections on Werner Bonefeld's 'Freedom and the Strong State: On German Ordoliberalism' and the Continuing Importance of the Ideas of Ordoliberalism to Understand Germany's (Contested) Role in Resolving the Eurozone Crisis." *New Political Economy* 18 (5): 768–78.

Bholat, D., S. Hansen, P. Santos, and C. Schonhardt-Bailey. 2015. *Text Mining for Central Banks: Handbook*. London: Centre for Central Banking Studies, Bank of England.

Bibow, J. 2013. "At the Crossroads: The Euro and Its Central Bank Guardian (and Saviour?)" *Cambridge Journal of Economics* 37 (3): 609–26.

Bistis, G. 2016. "From Karamanlis to Tsipras: The Greek Debt Crisis through Historical and Political Perspectives." *Mediterranean Quarterly* 27 (1): 30–54.

Blei, D. 2012. "Probabilistic Topic Models." *Communications of the ACM* 55 (4): 77–84.

Blinder A. S., M. Ehrmann, M. Fratzscher, J. De Haan, and D. Jansen. 2008. "Central Bank Communication and Monetary Policy: A Survey of Theory and Evidence." *Journal of Economic Literature* 46 (4): 910–45.

Boyd-Graber J., D. Mimno, and D. J. Newman. 2015. "Care and Feeding of Topic Models." In *Handbook of Mixed Membership Models and Their Applications*, ed. E. M. Airoldi, D. M. Blei, E. A. Erosheva, and S. E. Fienberg, 3–41. Boca Raton, FL: Taylor and Francis.

Brunnermeier, M. K., H. James, and J.-P. Landau. 2016. *The Euro and the Battle of Ideas.* Princeton, NJ: Princeton University Press.

Cao, J., T. Xia, J. Li, Y. Zhang, and S. Tang. 2009. "A Density-Based Method for Adaptive LDA Model Selection." *Neurocomputing* 72 (7–9): 1775–81.

Coenen, G., M. Ehrmann, G. Gaetano, P. Hoffmann, A. Nakov, S. Nardelli, E. Persson, and G. Strasser. 2017. "Communication of Monetary Policy in Unconventional Times." ECB Working Paper No. 2080.

Der Spiegel. 2012. "Ex-Währungshüter Stark attackiert EZB-Kurs." *Der Spiegel* 3. http://www.spiegel.de/wirtschaft/soziales/brandbrief-ex-waehrungshueter-stark-attackiert-ezb-kurs-a-809199.html.

Driffill, J., and Z. Rotondi. 2004. "Monetary Policy and Lexicographic Preference Ordering." CEPR Discussion Paper No. 4247.

Duca, J. 2017. "The Great Depression versus the Great Recession in the U.S.: How Fiscal, Monetary, and Financial Policies Compare." *Journal of Economic Dynamics and Control* 81 (August): 50–64.

Eichengreen, B. 2015. *Hall of Mirrors: The Great Depression, the Great Recession, and the Uses—and Misuses—of History*. New York: Oxford University Press.

———. 2016. "The Great Depression in a Modern Mirror." *De Economist* 164 (1): 1–17.

Eichengreen, B., and K. O'Rourke. 2010. "A Tale of Two Depressions: What Do the New Data Tell Us?" VoxEU.org (March 8). https://voxeu.org/article/tale-two-depressions-what-do-new-data-tell-us-february-2010-update.

Feld, L. P., E. A. Köhler, and D. Nientiedt. 2015. "Ordoliberalism, Pragmatism and the Eurozone Crisis: How the German Tradition Shaped Economic Policy in Europe." *Freiburger Diskussionspapiere zur Ordnungsökonomik* 15 (4): 1–25.

Friedman, M., and A. J. Schwartz. 1963. *A Monetary History of the United States, 1867-1960*. Princeton, NJ: Princeton University Press.

Grimmer, J., and B. M. Stewart. 2013. "Text as Data: The Promise and Pitfalls of Automatic Content Analysis Methods for Political Texts." *Political Analysis* 21 (3): 267–97.

Guiso, L., H. Herrera, and M. Morelli. 2016. "Cultural Differences and Institutional Integration." *Journal of International Economics* 99 (Supplement 1): S97–S113.

Haldane, A. and M. McMahon. 2018. "Central Bank Communications and the General Public." *AEA Papers and Proceedings* 108 (May): 578–83.

Hansen, P. H. 2015. "Hall of Mirrors: The Great Depression, the Great Recession, and the Uses—and Misuses—of History." *Business History Review* 89 (3): 557–69.

———. 2019. "Review Essay: The First History of Our Financial Crisis." *Business History Review* 93 (1, Spring): 161–71.

Hansen, S., and M. McMahon. 2016. "Shocking Language: Understanding the Macroeconomic Effects of Central Bank Communication." *Journal of International Economics* 99 (Supplement 1): S114–S133.

Hansen, S., M. Mcmahon, and A. Prat. 2018. "Transparency and Deliberation Within the FOMC: A Computational Linguistics Approach." *Quarterly Journal of Economics* 133 (2): 801–70.

Hansen, S., M. McMahon, and M. Tong. 2019. "The Long-Run Information Effect of Central Bank Communication." *Journal of Monetary Economics* 108 (December): 185–202.

Hansson, M. 2021. "Evolution of Topics in Central Bank Speech Communication." Working Paper in Economics No. 811, University of Gothenburg. https://EconPapers.repec.org/RePEc:hhs:gunwpe:0811 (accessed November 5, 2021).

Hartmann, P., and F. Smets. 2018. "The First Twenty Years of the European Central Bank: Monetary Policy." ECB Working Paper No. 2219.

Hesse, J. O., R. Köster, and W. Plumpe. 2015. *Die Große Depression. Die Weltwirtschaftskrise 1929–1939*. Bonn: Bundeszentrale für Politische Bildung.

Issing, O., V. Gaspar, I. Angeloni, and O. Tristani. 2001. *Monetary Policy in the Euro Area: Strategy and Decision-Making at the European Central Bank*. Cambridge: Cambridge University Press.

Küsters, A., L. Volkind, and A. Wagner. 2019. "Digital Humanities and the State of Legal History. A Text Mining Perspective." *Rechtsgeschichte—Legal History* 27: 244–59.

Loughran, T., and B. McDonald. 2011. "When Is a Liability Not a Liability? Textual Analysis, Dictionaries, and 10-Ks." *Journal of Finance* 66 (1): 35–65.

Lucas, C., R. Nielsen, M. Roberts, B. Stewart, A. Storer, and D. Tingley. 2015. "Computer Assisted Text Analysis for Comparative Politics." *Political Analysis* 23 (2): 254–77.

Masawi, B., S. Bhattacharya, and T. Boulter. 2014. "The Power of Words: A Content Analytical Approach Examining whether Central Bank Speeches Become Financial News." *Journal of Information Science* 40 (2): 198–210.

Meade, E. E., N. A. Burk, and M. Josselyn. 2015. "The FOMC Meeting Minutes: An Assessment of Counting Words and the Diversity of Views." *FEDS Notes* (May). https://www.federalreserve.gov/econresdata/notes/feds-notes/2015/fomc-meeting-minutes-an-assessment-of-counting-words-and-the-diversity-of-views-20150526.html (accessed June 18, 2020).

Mimno, D., H. M. Wallach, E. Talley, M. Leenders, and A. McCallum. 2011. "Optimizing Semantic Coherence in Topic Models." In *Proceedings of the 2011 Conference on Empirical Methods in Natural Language Processing*, ed. R. Barzilay and M. Johnson, 262–72. Edinburgh: Association for Computational Linguistics.

Mody, A. 2018. *EuroTragedy: A Drama in Nine Acts.* New York: Oxford University Press.

Morris, S., and H. S. Shin. 2002. "Social Value of Public Information." *American Economic Review* 92 (5): 1521–34.

Neustadt, R. E., and E. R. May. 1986. *Thinking in Time: The Uses of History for Decision-Makers.* New York: Free Press.

Noordegraaf-Eelens, L. H. J. 2010. "Contested Communication: A Critical Analysis of Central Bank Speech." ERIM Ph.D. Series Research in Management, Erasmus Research Institute of Management. https://repub.eur.nl/pub/21061/.

Qvigstad, J. F., and T. Schei. 2018. "Criteria for 'Good' Justifications." Research Working Paper No. 6, Norges Bank.

Reich, J., D. Tingley, J. Leder-Luis, M. E. Roberts, and B. M. Stewart. 2015. "Computer-Assisted Reading and Discovery for Student Generated Text in Massive Open Online Courses." *Journal of Learning Analytics* 2 (1): 156–84.

Ritschl, A. 2012. "War 2008 das neue 1929? Richtige und falsche Vergleiche zwischen der Großen Depression der 1930er Jahre und der Großen Rezession von 2008." *Perspektiven der Wirtschaftspolitik* 13 (Supplement): 36–57.

Roberts, M. E., B. M. Stewart, and E. Airoldi. 2016. "A Model of Text for Experimentation in the Social Sciences." *Journal of the American Statistical Association* 111 (515): 988–1003.

Roberts, M. E., B. M. Stewart, D. Tingley, C. Lucas, J. Leder-Luis, S. K. Gadarian, B. Albertson, and D. G. Rand. 2014. "Structural Topic Models for Open-Ended Survey Responses." *American Journal of Political Science* 58 (4): 1064–82.

Romer, C. 1992. "What Ended the Great Depression?" *Journal of Economic History* 52 (4): 757–84.

Shambaugh, J. 2012. "The Euro's Three Crises." *Brookings Papers on Economic Activity* 43 (1): 157–231.

Shiller, R. 2017. "Narrative Economics." *American Economic Review* 107 (4): 967–1004.

Silge, J. 2018. "Training, Evaluating, and Interpreting Topic Models." Julia Silge Blog. https://juliasilge.com/blog/evaluating-stm/ (accessed June 19, 2020).

Silge, J., and D. Robinson. 2017. *Text Mining with R: A Tidy Approach*. Sebastopol: O'Reilly Media.

Sum, K. 2016. *Post-Crisis Banking Regulation in the European Union: Opportunities and Threats*. Berlin: Palgrave Macmillan.

Sussman, L., P. Ricchio, and J. Belohlav. 1983. "Corporate Speeches as a Source of Corporate Values: An Analysis across Years, Themes, and Industries." *Strategic Management Journal* 4 (2): 187–96.

Taddy, M. 2013. "Multinomial Inverse Regression for Text Analysis." *Journal of the American Statistical Association* 108 (503): 755–70.

Takeda, Y., and M. Keida. 2018. "Central Bank Communication Strategies: A Computer Based Narrative Analysis of the Bank of Japan's Governor Kuroda." In *Hawks and Doves: Deeds and Words Economics and Politics of Monetary Policymaking*, ed. S. Eijffinger and D. Masciandaro, 137–42. London: VoxEU.org eBook.

Tetlock, P. C. 2007. "Giving Content to Investor Sentiment: The Role of Media in the Stock Market." *Journal of Finance* 62 (3): 1139–68.

Tooze, A. 2015. "How to Mishandle a Crisis." *New Left Review* 92 (Mar/Apr): 135–43.

Volkens, A., J. Bara, I. Budge, M. McDonald, and H. Klingemann. 2013. *Mapping Policy Preferences from Texts: Statistical Solutions for Manifesto Analysts*. Oxford: Oxford University Press.

Wehrheim, L. 2019. "Economic History Goes Digital: Topic Modelling the Journal of Economic History." *Cliometrica* 13 (1): 83–125.

Wickham, H., and G. Grolemund. 2017. *R for Data Science: Import, Tidy, Transform, Visualize, and Model Data*. Beijing: O'Reilly.

Woodford, M. 2005. "Central Bank Communication and Policy Effectiveness." NBER Working Paper No. 11898.

Trends in Monetary Policy Transparency: Further Updates

Nergiz Dincer,[a] Barry Eichengreen,[b] and Petra Geraats[c]
[a]TED University
[b]University of California, Berkeley
[c]University of Cambridge

We update our earlier index of monetary policy transparency, providing new estimates of political, economic, procedural, policy, and operational transparency for 112 central banks from 1998 through 2019. Central banks continue to move in the direction of greater transparency in their conduct of monetary policy. This is true for countries of different income levels. It is true regardless of monetary policy strategy, be this inflation targeting, monetary aggregate targeting, or exchange rate targeting, although the trend is least evident for the last of the three. This movement is also evident, to an extent, across all five of the dimensions of monetary policy transparency that we consider when constructing our aggregate index.

JEL Codes: E5, E52, E58.

1. Introduction

The last two decades—roughly speaking, the period since the Asian financial crisis—have seen a transparency revolution in central banking. The days when an official could say that the basis for a change in the central bank's policy rate was no more the business of the government and the public than "the color which the Bank painted its front door" are long past.[1] In earlier work (Dincer, Eichengreen, and Geraats 2019) we documented trends in monetary policy transparency, overall and along different dimensions (political, economic, procedural, policy, and operational) for 112 central banks in nearly

[1]The quotation is from Otto Niemeyer, advisor to the governor of the Bank of England, in 1929 (cited in Eichengreen, Watson, and Grossman 1985).

150 countries from 1998 to 2015. In this report, we revise and update these series through 2019.[2]

Throughout, we refer to monetary policy transparency as opposed to the more familiar terminology of central bank transparency. Many central banks have other functions in addition to the conduct of monetary policy, such as microprudential regulation and supervision, and increasingly, macroprudential policy. The criteria that are relevant for measuring the transparency of these other policies may well differ from those that are relevant for the transparency of monetary policy.[3] The feasibility, effects, and desirability of transparency may be different as well.[4]

We document further increases in monetary policy transparency in high-income countries, upper-middle-income countries, lower-middle-income countries, and low-income countries. We show that the years 2015–19 saw net increases in transparency by 41 central banks in our sample and net declines in just 6. We continue to see

[2]In the online appendix at https://eml.berkeley.edu/%7Eeichengr/data.shtml we also provide the complete set of individual central bank scores.

[3]Some pioneering work has been done on transparency in the domains of macroprudential and microprudential policies. Thus, Horváth and Vaško (2016) construct an index of the transparency of financial stability for 110 central banks between 2000 and 2011. Many of the patterns they uncover over time and across countries do, however, parallel those we report here. Arnone, Darbar, and Gambini (2007) and Liedorp et al. (2013) focus on the transparency of banking supervisors as opposed to the transparency of those responsible for the broader financial system, and cover not just financial stability but also other issues with which banking supervisors are concerned (such as consumer protection). Arnone, Darbar, and Gambini (2007) analyze the findings of the latest IMF–World Bank Financial Sector Assessment Program as of the end of 2004 for as many as 116 countries, finding that the transparency of banking supervision, as measured relative to the Basel Core Principles and the IMF Code on Transparency of Financial Policies, is positively associated with the effectiveness of bank supervision. Liedorp et al. (2013), inspired by the work of Eijffinger and Geraats (2006), code scores based on survey responses from 24 banking supervisors in the second half of 2010, but find it hard to identify factors accounting for differences in supervisory transparency across countries.

[4]Arguments regarding transparency of financial stability policy must factor in the danger that too much information about financial institutions may trigger destabilizing runs on individual financial institutions or even destabilize the system (Cecchetti and Disyatat 2010). Arguments for constructive ambiguity to limit moral hazard may be even more important in the context of financial supervision. Supervisors may also be subject to legal restrictions on their ability to release proprietary information.

marked increases in transparency for central banks that target inflation and monetary aggregates, but barely any increase for central banks that target the exchange rate. Between the two most recent years, 2018 and 2019, however, average transparency indices stayed almost the same except for monetary aggregate targeters and low-income countries, whose central banks have traditionally displayed lower levels of transparency and where there was a strong further rise.

2. Why Transparency Matters

It is worth recalling why central bank transparency matters. First, transparency is a mechanism for enhancing central bank accountability, which is a foundation stone of central bank independence. Extensive literatures concerned with the time inconsistency of optimal monetary policy (Kydland and Prescott 1977, Calvo 1978), special interest politics (Gabillon and Martimort 2004), and the political business cycle (Nordhaus 1975, Alesina 1988) have pointed to the advantages of central bank independence. These literatures emphasize the advantages of allowing those responsible for the formulation of monetary policy to make decisions autonomously (without undue influence from the executive or legislature, from financial institutions, and from other external stakeholders), while being guided by a socially and politically determined mandate. Transparency about the basis and justification for their decisions is a way for central bankers to explain how their actions are consistent with that mandate. Transparency is in this sense integral to their autonomy.[5]

Transparency in the service of accountability and autonomy is particularly important in an environment where central banks are making unprecedented interventions and resorting to unconventional policy tools, such as quantitative easing and negative interest rates.

[5]De Haan, Eijffinger, and Waller (2005) and De Haan et al. (2018) distinguish three aspects of central bank accountability: the central bank is accountable for faithfully pursuing its mandate; the central bank must disclose its monetary actions and how they relate to the mandate; and the central bank must accept final responsibility for monetary policy. The link between central bank transparency and accountability operates most directly through the second of these three channels. De Haan, Amtenbrink, and Eijffinger (1999) construct an index of central bank accountability, whereas we focus on the transparency aspects.

When the central bank has not done such things before, it may not be obvious to the executive, legislature, and public that these actions are consistent with the institution's mandate. Explaining and justifying policy actions may be especially important when those actions are novel and observers have limited prior experience to help with their interpretation.

Relatedly, transparency is integral to communication, which is an increasingly important policy tool in an environment where central banks attempt to steer inflation and the economy by shaping expectations about future policy. Examples include the announcement of quantified policy objectives (e.g., inflation or exchange rate targets) and providing forward guidance, which allows central banks to go beyond explaining just current policy decisions by providing an indication of likely future policy decisions. This may be especially important in a low interest rate environment where there is little space for the use of conventional monetary policy tools—that is to say, in the current policy environment. These and related issues are the focus of Blinder et al. (2017).

Finally, the forward guidance made possible by transparent communication may help central banks deal with the time-inconsistency problem that bedevils even conventional monetary policy. More generally, transparency and clear communication about the basis for policy decisions and objectives is a way of tightening the link between the central bank's immediate policy levers and the market interest rates and asset prices that affect the economic conditions that feature in the central bank's mandate (Ehrmann and Fratzscher 2009).

These arguments for central bank transparency find broad support in the scholarly literature and the central banking community.[6] They are the arguments that led the International Monetary Fund (2020b) to publish a new Central Bank Transparency Code, which

[6]There are exceptions and reservations, to be sure. For example, providing too much information may complicate communication and overload the public, weakening both the policy process and popular support for an independent central bank (Mishkin 2004). Collecting, collating, editing, and disseminating information, much less tailoring it to multiple audiences, can be costly for central banks, especially less well-resourced central banks in low-income countries (Filardo and Guinigundo 2008).

defines best practice and promulgates international standards in this area.[7]

2.1 How We Constructed Our Updates

We constructed our indices of monetary policy transparency utilizing the framework pioneered by Eijffinger and Geraats (2006) as extended by Dincer and Eichengreen (2014) and Dincer, Eichengreen, and Geraats (2019). These measures distinguish five aspects of central bank transparency.

- Political transparency refers to openness about policy objectives. Typically this involves a formal statement of objectives, including an explicit prioritization in case of multiple goals, quantification of the primary objective(s), and explicit institutional arrangements.
- Economic transparency refers to the economic information used in the formulation of monetary policy. This encompasses the economic data to which policymakers refer, the model(s) of the economy that they use to construct forecasts and evaluate the impact of their decisions, and the internal forecasts on which they rely.
- Procedural transparency refers to the manner in which monetary policy decisions are reached. This is coded on the basis of whether or not the central bank provides an explicit monetary policy rule or strategy that describes the monetary policy framework, and an account of monetary policy deliberations and how the policy decision was reached.
- Policy transparency captures whether or not the central bank promptly discloses its policy decisions and provides the associated explanation and rationale, and whether or not it provides forward guidance.
- Finally, operational transparency refers to the information the central bank provides about problems of policy implementation and execution. Typically, this takes the form of

[7] The Central Bank Transparency Code updates and supersedes the earlier Monetary and Financial Policies Transparency Code promulgated in 1999 in the immediate aftermath of the Asian financial crisis, that crisis being attributed by some to a lack of policy transparency in the region, as alluded to in the first sentence in our introduction.

> a discussion of control errors in achieving operating targets, unanticipated macroeconomic disturbances that affect the transmission of monetary policy, and evaluation of the results of previous policy initiatives.

Each dimension of transparency is captured by a sub-index that consists of three separate items, each of which receives a score of 0, 1/2, or 1. The overall index equals the sum of the scores across all items, ranging from 0 to a maximum of 15, and is based on information publicly available in English, the language of international financial markets.[8]

Compared to our earlier work on central bank transparency, here we adopt the same modifications that were proposed and implemented by Dincer, Eichengreen, and Geraats (2019). First, the transparency index explicitly focuses on monetary policy, as distinct from other central bank functions. This refinement, which mostly affects the political dimension, is more important now than in the past insofar as a growing number of central banks that once confined themselves to the formulation and execution of monetary policy have also started to implement macroprudential policies in pursuit of financial stability objectives.

Second, we use the more detailed coding of procedural and policy transparency introduced by Dincer, Eichengreen, and Geraats (2019). Thus, the 15 items of the index again distinguish 27 separate information disclosure practices.

The Dincer-Eichengreen-Geraats (2019) index adopted tighter criteria for procedural transparency relative to earlier work, because the financial crisis demonstrated the importance of timely information, especially in periods of heightened uncertainty. For instance, it is often important, for informational purposes, to know the rationale for a policy decision without undue delay. If circumstances are changing rapidly, minutes that are only released after the subsequent policy meeting are less useful and even potentially confusing. Consequently, full marks for this item require that comprehensive minutes (or explanations of the policy decision if there is a single central banker) are published within three weeks. The index gives

[8]All of the central banks in our sample other than that of the Central African Economic and Monetary Community have a website in English.

partial credit for summary minutes published within three weeks, or more comprehensive minutes published with a delay of more than three but less than eight weeks.

Likewise, the publication of individual voting records on the day of the policy announcement (or the policy decision made by a single central banker, which is equivalent) is required to get full credit for another procedural item. The index gives partial credit for the release of individual voting records within eight weeks or non-attributed voting records within three weeks.

Regarding policy transparency, the Dincer-Eichengreen-Geraats (2019) index adopted more demanding criteria with respect to forward guidance about the likely timing, direction, size, or pace of future monetary policy actions. A policy inclination or qualitative forward policy guidance gets only partial credit, whereas quantitative forward guidance about future policy actions is required for full marks. Examples of the latter include calendar-based guidance, state-contingent guidance based on numerical thresholds (both of which indicate the likely timing of the next change in the policy instrument but not necessarily the amount), or publication of the projected policy path, which is a more comprehensive form of time-dependent forward guidance.[9] Note that we focus on explicit forward guidance with respect to conventional monetary policy (although

[9]Readers may worry that forward guidance is a practice limited to inflation-targeting central banks, and that our index will therefore be biased against giving credit to central banks that target, inter alia, the exchange rate. Note, however, that the IMF categorization of "exchange rate targeters" includes not just central banks operating fixed exchange rate pegs but also those with target zones, crawling pegs, and other stabilized or managed exchange rate arrangements. In addition, nothing prevents a central bank targeting the exchange rate from communicating that it is likely to change its policy rate or intervene in the foreign exchange market in the future in order to maintain the currency peg. For example, the Monetary Authority of Singapore, which pegs its currency to an undisclosed basket, has published statements that resemble forward guidance. The National Bank of Denmark, which keeps the krone within a narrow band against the euro, communicated information about the future path of its foreign reserves (and therefore implicitly about intervention) when the Swiss National Bank abandoned its exchange rate ceiling in January 2015. These statements have the appearance of policy inclinations. To be given credit for providing an explicit policy inclination in our coding, however, central banks are required to communicate this regularly, which does not appear to be the case of exchange-rate-targeting central banks.

such guidance may in some cases be explicitly tied to a specific horizon for unconventional measures).[10] Again, all this follows Dincer, Eichengreen, and Geraats (2019). The main difference is that we have extended the sample period of our index by four years so that it now ends in 2019. Details on the coding are available in the online appendix (see footnote 2 for location of online appendix).

3. Findings

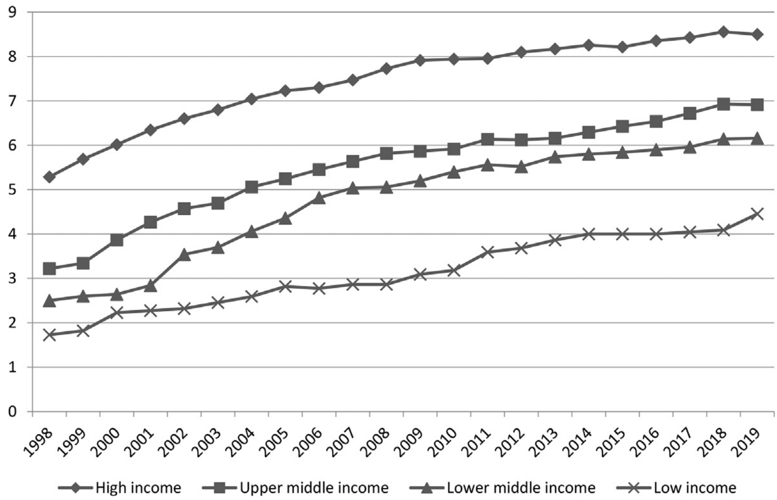
Figure 1 shows the levels and trends in our monetary policy transparency index from 1998 until 2019 for high-income, upper-middle-income, lower-middle-income, and low-income countries, based on the World Bank classification for fiscal year 2019.[11] It is evident that transparency tends to be increasing in the level of economic development and has been trending upward for all four groups. The gap between low-income countries and middle-income countries has increased, with the latter moving closer to the higher levels of transparency characteristic of high-income countries. For the lower-middle-income group, the convergence toward high-income levels of transparency is most pronounced in the first decade of the 21st century, while the upper-middle-income group experienced convergence during the second decade but not the first.

Figure 2 shows the levels and trends of our transparency index by monetary policy framework, distinguishing inflation targeters, exchange rate targeters, monetary aggregate targeters, and central banks with another or unspecified policy framework. We follow the IMF's (2020a) categorization of countries according to their de facto monetary policy framework. Inflation-targeting central banks have by far the highest level of monetary policy transparency on average, consistent with the idea that transparency and communication

[10]For instance, from July 2016 until April 2018 the European Central Bank stated that it expected its key interest rates to remain at current (or lower) levels "for an extended period of time, and well past the horizon of the net asset purchases," where it explicitly specified the intended minimum horizon of the latter under its asset purchase program.

[11]Using a single classification is important, since it means that the trends within groups we document are not caused by changes in group composition.

Figure 1. Transparency in Monetary Policy by Level of Economic Development (unweighted average)

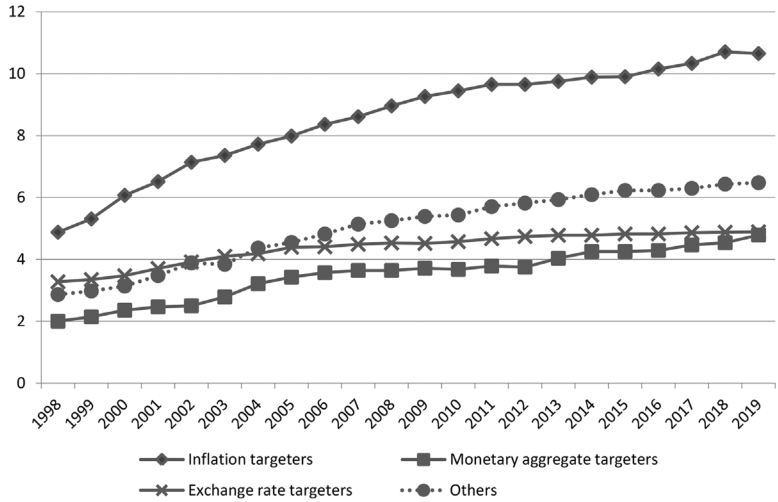


Source: Authors' calculations.
Note: Unweighted average monetary policy transparency index across central banks grouped by World Bank income classification (for fiscal year 2019). ECCU (Eastern Caribbean Currency Union), CEMAC (Central African Economic and Monetary Community), and WAEMU (West African Economic and Monetary Union) were classified by using GNI in U.S. dollars and population data of each country to compute GNI per capita for the region.

are integral to the framework; they also show the largest absolute increase in transparency, as measured by our index, over the two decades.

Central banks in the other three policy framework groups show smaller but substantial increases in transparency over the same period, although the exact timing differs across groups. The exchange rate targeters display the smallest increase overall. Apparently, exchange rate targeters feel less urgency about improving their information disclosure, perhaps because their monetary policy is automatically adjusted to maintain the exchange rate target, the achievement of which is easily observable. The increase in average levels of transparency for monetary aggregate targeters since 2013 has nearly erased the gap with exchange rate targeters, although the gap with the group of other/unspecified monetary rule central

Figure 2. Transparency by Monetary Policy Framework (unweighted average)



Source: Authors' calculations.
Note: Average monetary policy transparency index by IMF de facto monetary policy framework (IMF 2020a). Bermuda, Cayman Islands, Cuba, and Macao, which are not included in IMF classification, are excluded.

banks remains. Recall that the group with other (eclectic or undefined) monetary policy frameworks actually overtook the group of exchange rate targeters in terms of transparency during the first half of our sample period.

The period 2015–19 saw increases in transparency in fully 41 countries, as noted earlier.[12] The most transparent central banks circa 2019 are listed in Table 1. For some of these banks—those of Sweden, Norway, the Czech Republic, the euro area, the United

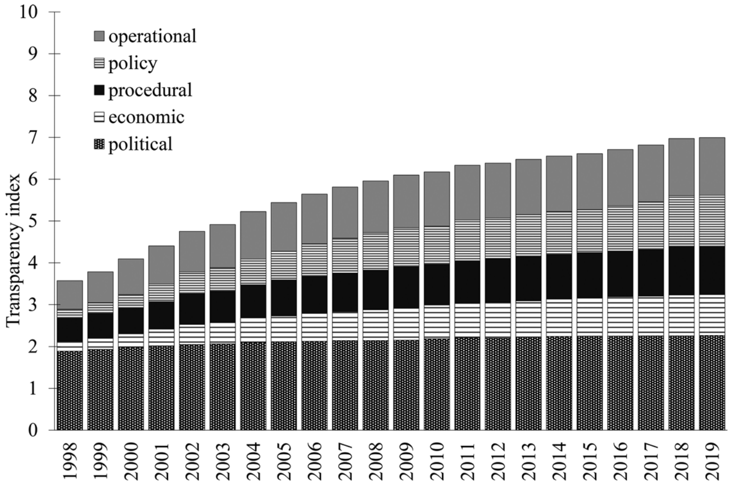
[12]The countries in question are Albania, Argentina, Azerbaijan, Belarus, Brazil, Chile, Columbia, Curaçao, Egypt, European Monetary Union, Georgia, Hong Kong, India, Indonesia, Israel, Jamaica, Japan, Kazakhstan, Korea, Macao, Malawi, Mauritius, Mexico, Moldova, Mongolia, Namibia, Norway, Pakistan, Peru, Romania, Russia, Rwanda, Saudi Arabia, Seychelles, Sierra Leone, South Africa, Sri Lanka, Trinidad Tobago, Ukraine, the United Arab Emirates, and the United Kingdom.

Table 1. Monetary Policy Transparency Index and Its Components in 2019 for the Top 12 Countries

	Transparency Index	1(a)	1(b)	1(c)	2(a)	2(b)	2(c)	3(a)	3(b)	3(c)	4(a)	4(b)	4(c)	5(a)	5(b)	5(c)
Sweden	14.5	1	1	1	0.5	1	1	1	1	1	1	1	1	1	1	1
Czech Republic	14	1	1	1	0.5	1	1	1	1	0.5	1	1	1	1	1	1
United Kingdom	13.5	1	1	1	0.5	1	1	1	1	1	1	1	0.5	1	1	0.5
Chile	13	1	1	1	0.5	1	1	1	1	1	1	1	0.5	1	0.5	0.5
Norway	13	1	1	1	0.5	1	1	1	0	0.5	1	1	1	1	1	1
Hungary	12.5	1	1	1	0.5	1	1	1	1	0.5	1	1	0.5	1	0.5	0.5
United States	12.5	0.5	1	0.5	1	1	1	1	1	1	1	1	1	1	0	0.5
European Monetary Union	12	1	1	1	0.5	1	1	1	0.5	0	1	1	1	1	0.5	0.5
Iceland	12	1	1	1	0.5	1	1	1	1	0.5	1	1	0	1	0.5	0.5
Japan	12	0.5	0.5	1	1	1	1	1	0.5	1	1	1	0.5	1	0.5	0.5
Korea	12	1	1	1	0.5	1	1	1	0.5	0.5	1	1	0.5	1	0.5	0.5
South Africa	12	1	1	1	0.5	1	1	1	0	0.5	1	1	1	1	0.5	0.5

Source: See text.
Note: Each of the five components of the transparency index is divided into three subcomponents denoted a, b, and c. For additional details, see Dincer, Eichengreen, and Geraats (2019).

Figure 3. Average Transparency Trends, Separate Dimensions (unweighted average)

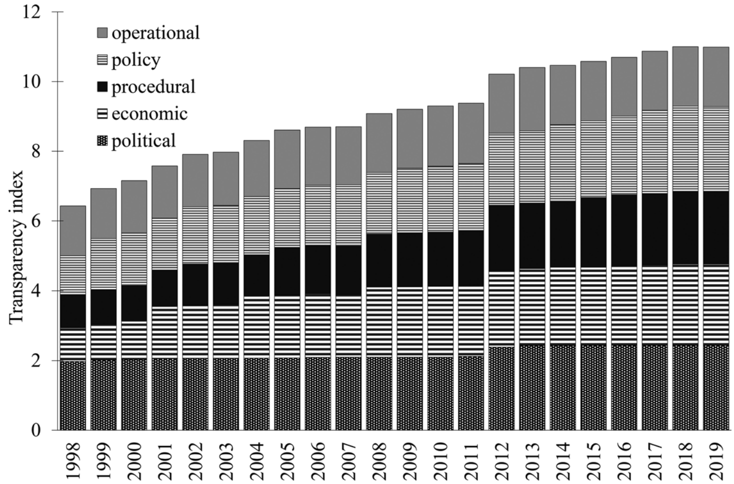


Source: See text.
Note: Unweighted average transparency index for all 112 central banks in the sample.

Kingdom, and the United States—high levels of monetary policy transparency are long standing. Other cases such as Hungary are more recent. The Sveriges Riksbank is currently the most transparent monetary policymaker in our sample of 112 central banks.

Figure 3 decomposes monetary policy transparency in our 112 central banks into its five functional components. We show there the unweighted average across central banks. For the entire period starting in 1998, there are increases in all five components, although the change is most dramatic for economic transparency (provision of information about data, models, and forecasts) and policy transparency (explanation of how policy strategies and instruments map into monetary policy goals). There is some sign of the extent of economic transparency leveling off in recent years. The increase over the entire period is least for political transparency (statements of what precisely those policy goals are), in part reflecting the fact that policy transparency was the one dimension on which central banks scored high at the beginning of the period.

Figure 4. Average Transparency Trends, Separate Dimensions (weighted average)



Source: See text.
Note: The transparency index for the world economy is constructed as the weighted average of the index across all central banks, using as weights their 2006 GDP shares in aggregate GDP in our sample, where GDP is in U.S. dollars and taken from the World Development Indicators of the World Bank. Due to unavailability of GDP for Curaçao, it is excluded from the sample.

Figure 4 instead weights the indices for individual countries by their purchasing-power-parity (PPP) GDP, giving heavier weights to larger and richer countries. The comparison with Figure 3 suggests that increases in transparency have slowed in recent years, as if much of the movement since 2015 has been in smaller, lower-income economies with relatively low transparency ratings previously.

Table 2 provides a breakdown of the number of central banks by type of information disclosure for each of the five dimensions of transparency in our index. The largest number of central banks, 89 in all, satisfy the criterion for procedural transparency that requires that they articulate an explicit monetary policy strategy. Many fewer are procedurally transparent in other respects (in releasing minutes, policy board voting totals, and individual member votes), although there was some additional movement in this direction between 2015 and 2019. Policy transparency also increased between

Table 2. Information Disclosure by Central Banks over Time

Number of Central Banks Disclosing Information on:	**1998**	**2006**	**2015**	**2019**
Political Transparency				
Formal Primary Objective(s with Prioritization)	60	66	71	72
Quantified Main Monetary Policy Objective(s)	37	52	61	61
Explicit Instrument Independence	41	54	60	62
Economic Transparency				
Macroeconomic Policy Model(s)	4	21	28	32
Numeric Macroeconomic Forecasts	9	49	68	70
Quarterly Medium-Term Inflation and Output Forecasts	4	15	29	32
Procedural Transparency				
Explicit Monetary Policy Strategy	51	79	89	89
Minutes (within Eight Weeks)	6	14	24	28
Comprehensive, Timely Minutes	2	10	17	20
Voting Balance/Records (within Three/Eight Weeks)	8	11	17	23
Prompt Individual Voting Records	4	6	6	8
Policy Transparency				
Prompt Announcement of Policy Adjustments	16	52	57	66
Explanation of Policy Adjustments	13	44	57	66
Always Explanation of Policy Decision	3	20	40	53
Qualitative Forward Guidance	0	4	9	11
Quantitative Forward Guidance	0	1	5	7
Operational Transparency				
Monetary Transmission Disturbances	14	46	56	59
Evaluation Monetary Policy Outcomes	32	61	69	69

Source: See text.
Note: Based on scores for individual components of transparency index for full sample of 112 central banks.

2015 and 2019, reflecting mainly the increased number of central banks promptly announcing policy adjustments, providing attendant explanations, and (most especially) doing so consistently. Least pronounced were increases in operational transparency (central banks explaining how problems with the transmission mechanism affect the implementation of monetary policy), political transparency (central banks releasing statements about objectives and instrument independence), and economic transparency (central banks releasing numerical forecasts of the variables of interest and describing the model used to generate those forecasts). But these aggregates all show at least modest movement in the direction of greater transparency.

Just six countries moved in the direction of less transparency. China continues to publish quarterly monetary policy reports (as it has since 2004), but since 2016 with a delay. Cuba continues to provide policy explanations on the central bank's webpage, but no longer in English. Denmark switched from publishing quarterly forecasts starting in 2008 to publishing semiannual forecasts starting in 2017, from which point it no longer published a quarterly report. Iceland, so far as we can tell, discontinued providing qualitative forward guidance in May 2019.[13] Kyrgyzstan and Macedonia did not always publish monetary policy reports and forecasts in a timely fashion. Most of these changes are slight. Some may reflect technical difficulties rather than conscious changes in policy transparency. They do not, in our view, represent a significant countercurrent against the general movement toward increased transparency.

Finally, it is worth commenting on developments in 2019, the most recent year covered in our analysis. This year saw a noticeable increase in monetary policy transparency in low-income countries, suggesting ongoing convergence toward the best practices of middle- and high-income countries. There was little change in high- and high-middle-income countries, but the balance of that change, somewhat surprisingly, was in the direction of less transparency. The small handful of negative changes observed related to the removal of explicit forward guidance, omitted forecasts, and failure to provide explanations for monetary policy actions.[14]

---

[13] Earlier forward guidance was replaced by less specific language stating that "near-term monetary policy decisions will depend on the interaction between developments in economic activity, on the one hand, and inflation and inflation expectations, on the other."

[14] Among high-income countries, the Central Bank of Israel did not publish a Research Department Forecast in October 2019, while Canada referred to various risks without continuing to provide explicit qualitative forward guidance. Iceland

4. Conclusion

In this report we have updated measures of monetary policy transparency, providing new estimates of political, economic, procedural, policy, and operational transparency for 112 central banks for the period 1998–2019. Central banks continue to move in the direction of greater monetary policy transparency. This is true for central banks in high-income, middle-income, and low-income countries alike. It is true regardless of stated monetary policy strategy, be this inflation targeting, monetary aggregate targeting, or exchange rate targeting, although the upward trend is least evident for central banks that peg the currency. This recent movement in the direction of greater transparency is evident, to some extent, across all five of the dimensions of monetary policy transparency that we consider when constructing our aggregate index. That said, additional transparency in recent years seems to reflect mainly further movement in this direction along the procedural dimension, as more central banks release minutes, increase the comprehensiveness and timeliness of those minutes, and provide additional information on monetary policy committee voting outcomes. It reflects mainly additional movement along the policy dimension, as more central banks promptly and regularly announce policy rate adjustments and promptly and consistently explain the underlying rationale.

Comparing practice over time when an unweighted average is taken across central banks and when national scores are weighted by PPP GDP indicates that the movement toward greater monetary policy transparency since 2015 has been concentrated disproportionately in smaller, lower-income countries that previously lagged in this dimension, while the smallest increases in this period were, understandably, in high-income countries that had already approached the transparency frontier. Evidently, the transparency revolution pioneered by the central banks of relatively high-income countries is continuing to diffuse to the rest of the world.

replaced previous forward guidance with statements to the effect that future policy developments will depend on events. Among upper-middle-income countries, the central bank of Azerbaijan did not include a macroeconomic forecast in 2019, while Cuba did not provide an English-language monetary policy explanation on its webpage.

References

Alesina, A. 1988. "Macroeconomics and Politics." In *NBER Macroeconomic Annual,* Vol. 3, ed. S. Fischer, 13–62 (chapter 1). MIT Press.

Arnone, M., S. Darbar, and A. Gambini. 2007. "Banking Supervision: Quality and Governance." IMF Working Paper No. 07/82 (April).

Blinder, A., M. Ehrmann, J. de Haan, and D. Jansen. 2017. "Necessity as the Mother of Invention: Monetary Policy after the Crisis." *Economic Policy* 32 (92): 707–55.

Calvo, G. 1978. "On the Time Consistency of Optimal Policy in the Monetary Economy." *Econometrica* 46 (6): 1411–28.

Cecchetti, S., and P. Disyatat. 2010. "Central Bank Tools and Liquidity Shortages." *Economic Policy Review* (Federal Reserve Bank of New York) 16 (1, August): 29–42.

De Haan, J., F. Amtenbrink, and S. Eijffinger. 1999. "Accountability of Central Banks: Aspects and Quantification." *Banca Nazionale del Lavoro Quarterly Review* 52 (209): 169–93.

De Haan, J., C. Bodea, R. Hicks, and S. Eijffinger. 2018. "Central Bank Independence Before and After the Crisis." *Comparative Economic Studies* 60 (2): 183–202.

De Haan, J., S. Eijffinger, and S. Waller. 2005. *The European Central Bank: Centralization, Transparency and Credibility.* Cambridge, MA: MIT Press.

Dincer, N., and B. Eichengreen. 2014. "Central Bank Transparency and Independence: Updates and New Measures." *International Journal of Central Banking* 10 (1, March): 189–253.

Dincer, N., B. Eichengreen, and P. Geraats. 2019. "Transparency of Monetary Policy in the Postcrisis World." In *The Oxford Handbook of the Economics of Central Banking*, ed. D. G. Mayes, P. L. Siklos, and J.-E. Sturm, 287–336. New York: Oxford University Press.

Ehrmann, M., and M. Fratzscher. 2009. "Explaining Monetary Policy in Press Conferences." *International Journal of Central Banking* 5 (2, June): 41–84.

Eichengreen, B., M. Watson, and R. Grossman. 1985. "Bank Rate Policy under the Interwar Gold Standard: A Dynamic Probit Model." *Economic Journal* 95 (379): 725–45.

Eijffinger, S., and P. Geraats. 2006. “How Transparent are Central Banks?” *European Journal of Political Economy* 22 (1): 1–22.

Filardo, A., and D. Guinigundo. 2008. “Transparency and Communication of Monetary Policy: A Survey of Asian Central Banks.” Unpublished Manuscript, Bank for International Settlements (April).

Gabillon, E., and D. Martimort. 2004. “The Benefits of Central Bank’s Political Independence.” *European Economic Review* 48 (2): 353–78.

Horváth, R., and D. Vaško. 2016. “Central Bank Transparency and Financial Stability.” *Journal of Financial Stability* 22 (February): 45–56.

International Monetary Fund. 2020a. *Annual Report on Exchange Arrangements and Exchange Restrictions 2019.* Washington, DC: International Monetary Fund.

———. 2020b. “The Central Bank Transparency Code.” IMF Policy Paper No. 2020/038 (July).

Kydland, F., and E. Prescott. 1977. “Rules Rather than Discretion: The Inconsistency of Optimal Plans.” *Journal of Political Economy* 85 (3): 473–92.

Liedorp, F., R. Mosch, C. van der Cruijsen, and J. de Haan. 2013. “Transparency of Banking Supervisors.” *IMF Economic Review* 61 (2): 310–35.

Mishkin, F. 2004. “Can Central Bank Transparency Go Too Far?” In *The Future of Inflation Targeting*, ed. C. Kent and S. Guttmann. Sydney: Reserve Bank of Australia.

Nordhaus, W. 1975. “The Political Business Cycle.” *Review of Economic Studies* 42 (2): 169–90.