Rule-of-Thumb Consumers and Labor Tax Cut Policy at the Zero Lower Bound*

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This paper shows that a labor tax cut can increase output in a model where the zero lower bound on the nominal interest rate binds due to a negative demand shock. The model is a basic New Keynesian one with non-Ricardian (also known as rule-of-thumb) households (along with the usual Ricardian ones) who spend the increase in their disposable income after the tax cut. Besides price rigidity, our result requires wage rigidity which attenuates the effect of the negative demand shock on the real wage. This finding stands in contrast to those of Eggertsson (2011) and Christiano, Eichenbaum, and Rebelo (2011), whose models support an increase in the labor tax. This paper departs from the assumption of balanced government budget with lump-sum taxes and introduces endogenous debt that is retired by taxes on labor income. It is shown that the tax-cut policy is most effective when debt is paid back far in the future.

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1. Introduction

Following the enactment of the American Recovery and Reinvestment Act (ARRA) of 2009, which is a $787 billion fiscal package containing labor tax cuts[1] and various forms of government purchases, there has been discussion on the sign and magnitude of fiscal multipliers. On one hand, some influential papers using New Keynesian type models featuring price rigidity concluded that an increase in non-productive government spending can be very effective in stimulating the economy under the zero lower bound (ZLB) which is binding in the United States since the end of 2008 (see, e.g., Christiano, Eichenbaum, and Rebelo 2011; Eggertsson 2011; and Woodford 2011). On the other hand, these papers found that labor tax cuts can be contractionary when the zero lower bound on the nominal interest rate is binding.

This paper contributes to the literature on fiscal policy at the zero lower bound by showing that the incorporation of rule-of-thumb (or non-Ricardian) consumers into the baseline New Keynesian model can render labor tax cut policy expansionary when the nominal interest rate is zero. Non-Ricardian households behave in a Keynesian fashion—i.e., they are willing to raise their consumption expenditure in response to a rise in their disposable income following the tax cut[2]—whereas Ricardians recognize that the tax cut in the present is covered by taxes in the future and therefore their whole lifetime income on which they base their consumption decision is not affected. In this paper we reduce the employees' part of the labor taxes similar to what is prescribed by the U.S. stimulus package of 2009.

First, let us discuss what the baseline log-linear New Keynesian model with only price rigidity and a perfectly competitive labor market with flexible wages delivers in the absence of non-Ricardian

[1]In December 2011 President Obama announced that the payroll tax cut would be extended until the end of 2012.

[2]Rule-of-thumb households are excluded from the financial market. Hence, they have no consumption-savings trade-off (lack of Euler equation) and their decision problem is restricted to the optimal choice between consumption and leisure. The inclusion of rule-of-thumb households into dynamic stochastic general equilibrium (DSGE) models is a trivial way of generating incomplete asset markets.

consumers in response to a labor tax cut. As in Christiano, Eichenbaum, and Rebelo (2011), the zero lower bound on the nominal interest rate becomes binding due to a discount factor shock (i.e., a negative demand shock) which leads to deflation and a fall in output, consumption, and the marginal cost. In a similar model, Eggertsson (2011) shows that cutting the labor tax rate has effects similar to the discount factor shock, i.e., a random fraction of firms that can change their product price will lower the price because they face a reduction in their production costs, while other firms that cannot reset their price due to price stickiness will produce less and also decrease their demand for labor. When the nominal interest rate is zero, the deflationary effect of the labor tax cut is coupled with a rise in the real interest rate that depresses consumption. Also, Ricardian consumers associate the current tax cut with future rises in taxes and decrease their consumption to save up (Ricardian equivalence is valid). Thus, with only Ricardian consumers in the model, the tax cut cannot be stimulative.

However, the labor tax cut happens to be expansionary if we incorporate non-Ricardian consumers and wage rigidity into the model. Following the tax cut, non-Ricardian households consume the rise in their disposable income, generating a demand effect. Due to the higher consumption demand of non-Ricardian households, firms which cannot alter their price as a result of price rigidity will demand more labor to be able to produce more. In the absence of an imperfectly competitive labor market with nominal wage inertia,[3] the discount factor shock and the labor tax cut would lead to an enormous decline in the marginal cost (which equals the real wage due to the constant-returns-to-scale production function in the absence of productivity shocks and physical capital). But the introduction of wage rigidity into the model attenuates the reaction of real wage to the discount factor shock so that the real disposable income of non-Ricardians can rise following the tax cut. Hence, in our setting the effects of the negative demand shock are less severe if there

[3]To motivate imperfectly competitive labor markets, households (independently of whether they are of Ricardian or non-Ricardian origin) become members of unions which set wages for them. It is costly for the unions to change wages because of wage adjustment costs. Hence, we have nominal wage rigidity. See details in the main text.

is a simultaneous fall in the labor tax during the zero-lower-bound period. Our finding is completely in contrast to Christiano, Eichenbaum, and Rebelo (2011), who argue in favor of a labor tax rise at the zero lower bound using a middle-sized DSGE model without rule-of-thumb agents.

In this paper we consider two different ways of financing the labor tax cut. First, we maintain the simplest fiscal scenario whereby the government budget is balanced in each period by lump-sum taxes paid only by Ricardians. Secondly, we depart from a balanced budget and introduce endogenous government debt which is retired through labor income taxes levied uniformly on both types of households and collected either in the short or long run. In the first case, a labor tax cut stimulates the economy by construction. In the second case tax cut policy boosts economic activity only when debt is paid back in the long run so that non-Ricardians can enjoy higher disposable income due to the tax cut in the present. An alternative interpretation is that non-Ricardians receive a transfer from Ricardians in the present, which is followed by a transfer from non-Ricardians to Ricardians in the future.

Again it needs to be emphasized that the tax cut is stimulative in this paper because we reduce the employees' part of the labor taxes, which leads to an increase in non-Ricardians' income and a rise in labor demand. In general, it matters a lot whether we cut the employer's or the employee's part of the labor taxes. In the latter case an average labor tax cut acts like a traditional stimulus tax cut working through the labor demand while the labor supply is of reduced importance due to wage-setting frictions in the model (Christiano 2011). However, in the previous case the payroll tax cut directly affects the marginal cost and, as we argue below, acts like a further deflationary factor on the economy besides the negative demand shock. Therefore, in this paper, it is the employee's part of the average labor tax which is reduced.

Our findings are based on deterministic labor tax cut experiments conducted using the shooting algorithm of Christiano, Eichenbaum, and Rebelo (2011), who studied small and middle-sized New Keynesian models in log-linear form without non-Ricardian consumers. Thus, in our experiments the discount factor shock and the fiscal action (the labor tax cut) are on for a deterministic period of time. This modeling strategy received considerable attention in the recent literature. Here we touch upon two issues. First, Carlstrom, Fuerst, and Paustian (2012) assert that inflation and output impulse responses of a negative demand shock might exhibit unorthodox behavior—they rise instead of falling—depending on the number of periods for which the interest rate is fixed when there are state variables such as price indexation in the log-linear model. However, we do not encounter such a problem for our calibrated value of the length of the shock.[4] Second, a number of papers[5] raise concerns about the accuracy of the first-order perturbation in modeling the zero lower bound. However, Christiano and Eichenbaum (2012) present evidence that first-order perturbation remains to be a fairly good approximation to the non-linear model.

This work is closely related to several papers in the literature. One of them is Coenen et al. (2012), who simulate various middle-sized DSGE models including rule-of-thumb households. We differ from that paper for at least two reasons. First, the zero-lower-bound period in our paper is generated endogenously as a result of a negative demand shock instead of arbitrarily fixing the interest rate for a given time period as Coenen et al. (2012) and Cogan et al. (2010) did. Siemsen and Watzka (2013) describe why it is misleading to model the ZLB in a way that Coenen et al. (2012) did. Even with an increase in government spending output, consumption and inflation are below their steady-state values due to the negative demand shock that makes the zero lower bound binding in Christiano, Eichenbaum, and Rebelo (2011) and, thus, real activity and inflation remain depressed even after the zero-lower-bound period. However, the same variables in Coenen et al. (2012) are above their steady state even during the zero lower bound in the absence of the negative demand shock, and therefore monetary policy has to tighten outside the zero-lower-bound period as the Taylor rule, which engineers a sharp increase in real interest rates, is in operation. In contrast, economic activity in Christiano, Eichenbaum, and Rebelo

[4]Depending on the size and length of the discount factor and the fiscal shock (tax cut), the model endogenously generates the date at which the zero lower bound starts and ceases to bind.

[5]See, e.g., Braun and Körber (2011) who, using a non-linear model, argue that the ignorance of price adjustment cost in the aggregate feasibility constraint distorts the size and even the sign of fiscal multipliers obtained from the log-linear model in which the price adjustment cost is zero.

(2011) still remains weak in the aftermath of zero interest rates, and therefore monetary policy can be slack (real interest rates are low). Second, we employ simpler models than Coenen et al. (2012) so that we can provide intuition on what model features are needed in order for the labor tax cut policy to be expansionary.

Our paper is also closely related to Bilbiie, Monacelli, and Perotti (2012), who have shown that cuts in lump-sum taxes stimulate output and raise welfare in an economy featuring two types of households (savers and borrowers) and price rigidity, and which is constrained by the zero lower bound on the nominal interest rate. This paper is also related to the literature on models containing rule-of-thumb consumers, such as Bilbiie (2008) and Galí, Lopez-Salidó, and Vallés (2007). The model used in this paper is closest to Ascari, Colciago, and Rossi (2011) and Furlanetto (2011), who enrich the model of Galí, Lopez-Salidó, and Vallés (2007) with wage-setting frictions.

There is a growing empirical literature which finds labor tax cuts stimulative. In a well-known study, using a narrative approach, Romer and Romer (2010) found that tax increases are contractionary. Also, Mertens and Ravn (2012) found, using a new narrative account of federal tax liability changes to proxy tax shocks, that the short-run effects of a tax decrease on output are positive and large. Hall (2009) reviews several empirical studies arguing that households do respond with an increase in their consumption expenditures to a temporary cut in labor tax. Thus, there is enough empirical evidence in support of the positive effects of a labor tax cut.

The rest of the paper is organized as follows. Section 1 describes the agents in the model and their assumed behavior. Section 2 contains the calibration. In section 3 we conduct experiments in various models to investigate the effects of the labor tax cut. The last section concludes.

2. The Model

2.1 Households

2.1.1 Ricardians

There are two types of households: Ricardians and non-Ricardians. Ricardian households are able to smooth their consumption using state-contingent assets (risk-free bonds), while non-Ricardians cannot. The share of Ricardian and non-Ricardian households in the economy is $1-\lambda$ and λ, respectively. The instantaneous utility function of type $i \in \{o, r\}$ household, which can be Ricardian (optimizer (OPT), o) or non-Ricardian (rule-of-thumb (ROT), r), is given by

$$U_t^i = \frac{(C_t^i - h_i \bar{C}_{t-1}^i)^{1-\sigma} - 1}{1-\sigma} - \frac{(N_t^i)^{1+\varphi}}{1+\varphi}, \tag{1}$$

where $C_t^i(\bar{C}_t^i)$ denotes the time-t consumption (aggregate consumption) of type $i \in \{o, r\}$ household and parameter $h_i > 0$ governs the degree of habit formation in consumption. When $h_i = 0$, there is no habit formation. σ is the inverse of the intertemporal elasticity of substitution (IES), which measures the willingness of households' substituting consumption across time. Further σ stands for relative risk aversion. N_t^i is hours worked by household of type i. The second term on the right-hand side of equation (1) denotes the disutility of household i from working. The Frisch elasticity of labor supply is given by $1/\varphi$.

First, we discuss the problem of Ricardian households. They maximize their lifetime utility,

$$E_0 \sum_{t=0}^{\infty} \beta_t U_t^i, \tag{2}$$

where E_0 is the expectation operator representing expectations conditional on period-0 information and β is the discount factor. This maximization of the optimizer household is subject to a sequence of budget constraints[6]:

$$P_t C_t^o + R_t^{-1} B_{t+1}^o = (1-\tau_t^o) W_t N_t^o + D_t^o + B_t^o - P_t T_t^o - F_t - P_t S^o,$$

where P_t is the aggregate price level, W_t is the nominal wage, and N_t^o is hours worked by OPT. Thus, $W_t N_t^o$is the labor income received by the optimizer household. T_t^o are lump-sum taxes (or transfers, if

[6]For the rest of the paper, a variable without a time subscript denotes steady-state value.

negative) paid by the Ricardian household (hence, the superscript o). τ_t^o is a tax rate on labor income ($W_t N_t^o$). Profit income is denoted by D_t^o. Further, B_{t+1}^o is the amount of risk-free bonds and R_t is the gross nominal interest rate. Following Galí, Lopez-Salidó, and Vallés (2007) we assume, without loss of generality, that the steady-state lump-sum taxes (S^o) are chosen in a way that steady-state consumption of ROT and OPT households are equal in steady state. Hence, S^o is a steady-state lump-sum tax used to facilitate the equality of the steady-state consumptions of ROT and OPT households. F_t stands for a nominal union membership fee (see more on it below). For an alternative approach when steady-state consumptions are not equal, see Natvik (2012).

In summary, the optimizer household maximizes its lifetime utility with respect to its budget constraint.

The OPT household first-order conditions (FOCs) with respect to consumption (C_t^o) and bonds (B_{t+1}^o) are

$$\frac{\partial U_t^i}{\partial C_t^i} = (C_t^i - h_i \bar{C}_{t-1}^i)^{-\sigma} = \lambda_t, \text{ with } i = o, \tag{3}$$

$$\beta_{t+1} E_t \left(\lambda_{t+1} \frac{R_{t+1}}{\pi_{t+1}} \right) = \lambda_t, \tag{4}$$

where λ_t is the marginal utility of consumption. In all the above equations that contain expectations, we ignore covariance terms.

The linearized[7] version of equation (4) is the intertemporal Euler equation:

$$c_t^o = \frac{h_o}{1+h_o} c_{t-1}^o + \frac{1}{1+h_o} E_t c_{t+1}^o - \frac{1-h_o}{1+h_o} \frac{\beta}{\sigma} [dR_t - E_t \pi_{t+1} - r_t^*], \tag{5}$$

where $c_t^o \equiv \log(C_t^o/C), \pi_t \equiv \log(P_t/P_{t-1})$ is the time-t rate of inflation, and $dR_t \equiv R_t - R$, i.e., the deviation of nominal interest rate from its steady-state value. r_t^* can be interpreted as the discount

[7]The fact that Eggertsson (2011) log-linearizes while Christiano (2011) linearizes the same model does not affect the main conclusions. Here we follow the latter strategy.

factor shock.[8] Notice that $h_o = 0$ delivers the usual Euler equation without habit formation.

The labor supply of OPT household is determined by the union's problem (discussed below).

2.1.2 Non-Ricardians

Non-Ricardian households cannot invest in bonds. In other words, they are excluded from financial markets. Hence, this is the case of limited asset market participation. Therefore, ROT do not make consumption-savings decisions (i.e., the lack of consumption Euler equation). ROT households' consumption depends on their disposable income—i.e., the labor income after taxation, $(1-\tau_t^r)W_tN_t^r$—which is reflected by their budget constraint:

$$\int_0^1 P_t(i)C_t^r(i)di = (1-\tau_t^r)W_tN_t^r - P_tS^r, \tag{6}$$

where $C_t^r(i)$ and N_t^r are, respectively, the consumption of product i and hours worked by rule-of-thumb households. The steady-state lump-sum tax, S^r, ensures that the steady-state consumption of each type of household coincides.

ROT agents exploit relative price differences in the construction of their consumption basket and, in optimum, they obtain

$$P_tC_t^r = \int_0^1 P_t(i)C_t^r(i)di.$$

[8] Following the appendix of Christiano (2011), the time-varying discount factor is made equal to the inverse of the real interest rate (R_t^{real}):

$$\beta_t = \frac{1}{1+R_t^{\mathrm{real}}},$$

which can be linearized as

$$\beta\hat{\beta}_t = -\frac{1}{(1+r)^2}r_t^*,$$

where $\hat{\beta}_t \equiv (\beta_t - \beta)/\beta$ and $r_t^* \equiv R_t^{\mathrm{real}} - R^{\mathrm{real}}$. It follows by using the steady-state condition $\beta = 1/(1+R^{\mathrm{real}}) = 1/(1+R)$ that

$$\hat{\beta}_t = -\beta r_t^*.$$

Thus, an ROT household maximizes its utility (equation (2) with $i = r$) with respect to its budget constraint (equation (6)).

The budget constraint of ROT households in equation (6) can be expressed in linear form as

$$c_t^r = w_t + n_t^r - \chi \hat{\tau}_t^r, \tag{7}$$

where $\hat{\tau}_t^r \equiv \tau_t^r - \tau^r$, $\chi \equiv 1/(1-\tau^r)$.

ROT households delegate their labor supply decision to unions.

2.2 Firms

The intermediary goods are produced by monopolistically competitive firms of which a randomly selected $1 - \xi^p$ fraction is able to set an optimal price each period as in Calvo (1983) while the remaining ξ^p fraction keep their price fixed. Intermediary good j, denoted as $Y(j)$, is produced by a one-to-one production function:

$$Y_t(j) = N_t(j), \tag{8}$$

where $N_t(j)$ is an aggregator of different labor varieties:

$$N_t(j) = \left(\int_0^1 [N_t(j,z)]^{\frac{\varepsilon_w - 1}{\varepsilon_w}} dz \right)^{\frac{\varepsilon_w}{\varepsilon_w - 1}},$$

where $N_t(j,z)$ stands for quantity of variety z labor employed by firm j. The one-to-one (constant-returns-to-scale) production function in equation (8) implies that the average (or economy-wide) marginal cost is equal to the economy-wide real wage in the absence of technology shocks.

There is a competitive firm which bundles intermediate goods into a single final good through the Kimball (1995) aggregator:

$$\int_0^1 \mathcal{G}(X_t(j))dj = 1, \tag{9}$$

where $X_t(j) \equiv Y_t(j)/Y_t$ is the relative demand and $\mathcal{G}$ is a function with properties $\mathcal{G}(1) = 1$, $\mathcal{G}' > 0$, and $\mathcal{G}'' < 0$. With Kimball specification, the elasticity of demand is increasing in the price $(P_t(j))$ set by an individual firm or, equivalently, decreasing in its relative output $(X_t(j))$. After linearization, it turns out that Kimball demand reduces the slope of the Phillips curve (see more below). The Kimball aggregator is also present in popular middle-sized DSGE models, such as the Smets-Wouters (2007) model.[9]

The profit-maximization problem of the perfectly competitive goods bundler (final goods producer) gives way to the relative demand for the product of firm j:

$$X_t(j) = \tilde{\mathcal{G}}\left(\frac{P_t(j)Y_t}{\mu_{f,t}}\right), \tag{10}$$

where $\tilde{\mathcal{G}} \equiv \mathcal{G}'^{-1}(.)$ and $\mu_{f,t}$ is the multiplier on the constraint (equation (9)) in the Lagrangean representation of the final goods producer's maximization problem (more details can be found in online appendix A at https://sites.google.com/site/lorantkaszab/research).

Intermediary firm z that last reset its price at time $T = 0$ maximizes its present and discounted future profits with the probability of not resetting its price:

$$\max_{P_t^*} \sum_{T=0}^{\infty} \left(\xi^p \beta\right)^T \Lambda_{t,t+T}\left[P_t^*(j)Y_{t+T}(j) - TC\left(Y_{t+T}(j)\right)\right], \tag{11}$$

where P_t^* is the optimal reset price at time t, ξ^p is the probability of not resetting the price, TC stands for the total cost of production, and $\Lambda_{t,t+T}$ is the stochastic discount factor defined as

$$\Lambda_{t,t+T} \equiv \left(\frac{C^o_{t+T} - h_o C^o_{t+T-1}}{C^o_{t+T+1} - h_o C^o_{t+T}}\right)^{\sigma} \frac{P_t}{P_{t+T}}.$$

This firm's maximization problem is subject to the production function in equation (8) and to the demand function of good z in equation (10).

The New Keynesian price Phillips curve in the case of Kimball demand can be written as

$$\pi_t = \beta E_t \pi_{t+1} + \kappa s_t \text{ with } \kappa \equiv A\frac{(1-\xi^p)(1-\beta\xi^p)}{\xi^p} \text{ and}$$

$$A \equiv \frac{1}{1+\mathcal{I}\frac{\epsilon}{\varepsilon_p - 1}}, \tag{12}$$

[9]There are several alternative ways to introduce strategic complementarity into price setting. In this paper we use the Kimball aggregator. Firm-specific labor is another possibility (see, e.g., chapter 3 in Woodford 2003).

where we can see that the slope of the Phillips curve (κ) is influenced beyond the Calvo parameter (ξ^p) and the discount factor (β) by the Kimball curvature parameter (ϵ) and the elasticity of demand (ε_p). The indicator variable $\mathcal{I}$ is equal to one when there is strategic complementarity in price setting (due to Kimball demand). The case of $\mathcal{I} = 0$ delivers the standard Phillips curve without Kimball demand. (For detailed derivation of the New Keynesian Phillips curve, see online appendix A.) In experiment 1 (see below), which utilizes the above model without wage stickiness, we found that real rigidity is necessary because it helps to avoid a non-uniqueness problem (for more on this, see footnote 18). Now we proceed to discuss the determination of labor supply.

2.3 Unions

To introduce wage stickiness into the model, one usually assumes that households have monopoly power in determining their wage as in Erceg, Henderson, and Levin (2000), who presume that each household can engage in perfect consumption smoothing. However, the presence of ROT households that cannot engage in intertemporal trade precludes the possibility of consumption smoothing. To motivate the wage-setting decision, we follow Galí, Lopez-Salidó, and Vallés (2007), whose model features a continuum of unions (on the unit interval), $z \in [0, 1]$, each representing a continuum of workers of which a fraction (λ) are members of rule-of-thumb and the remaining $(1 - \lambda)$ fraction consists of optimizing households. Each union employs one particular type of labor (independently of the type of households they originate from) that is different from the type of labor offered by other unions.

Each period, the union maximizes the weighted current and discounted future utility of its members:

$$E_t \sum_{T=0}^{\infty} \beta^T \left[\lambda U^r_{t+T} + (1 - \lambda) U^o_{t+T}\right]$$

subject to the labor demand function for labor of type z:

$$N_t(z) = \left(\frac{W_t(z)}{W_t}\right)^{-\varepsilon_w} N_t,$$

where $W_t(z)$ is the nominal wage set by the union z, ε_w is the elasticity of labor demand, and W_t is an aggregate of the wages set by unions:

$$W_t \equiv \left(\int_0^1 [W_t(z)]^{1-\varepsilon_w} \right)^{\frac{1}{1-\varepsilon_w}}.$$

Adjusting wages is costly, as in Rotemberg (1982), who originally applied it to model price adjustment. In particular, there is a wage adjustment cost which is a quadratic function of the change in the nominal wage and proportional to the aggregate wage bill. The presence of this wage adjustment cost is justified by the fact that unions have to negotiate wages each period and this activity consumes real resources. The larger is the increase in nominal wage achieved by the union, the higher is the effort associated with it. Each union member incurs an equal share of the wage adjustment cost. Thus, the nominal membership fee, F, paid by a generic union member z at time t is given by

$$F_t(z) = \frac{\phi_w}{2} \left(\frac{W_t(z)}{W_{t-1}(z)} - 1 \right)^2 W_t N_t,$$

where ϕ_w governs the size of the adjustment costs. In the special case of $\phi_w = 0$, the labor market features flexible wages.

The optimality condition from the union's problem can be derived by taking the FOC with respect to the wage, $\tilde{W}_t$:

$$\begin{aligned} 0 = & \left(\lambda \frac{\partial U_t^r}{\partial C_t^r} + (1-\lambda) \frac{\partial U_t^o}{\partial C_t^o} \right) (1-\tau_t) \tilde{W}_t [(\varepsilon_w - 1) + \phi_w (\Pi_t^w - 1) \Pi_t^w] \\ & - \varepsilon_w N_t^{\varphi} \\ & - \beta \left(\lambda \frac{\partial U_{t+1}^r}{\partial C_{t+1}^r} + (1-\lambda) \frac{\partial U_{t+1}^o}{\partial C_{t+1}^o} \right) \phi_w (\Pi_{t+1}^w - 1) \Pi_{t+1}^w \frac{W_{t+1}}{P_{t+1}} \frac{N_{t+1}}{N_t}, \end{aligned} \tag{13}$$

where $\Pi_t^w \equiv W_t / W_{t-1}$ is the wage inflation, $\tilde{W}_t \equiv W_t / P_t$ is the real wage, and $\frac{\partial U_t^i}{\partial C_t^i}$ is defined by equation (3) for $i \in \{o, r\}$. In deriving equation (13), we assumed that the labor taxes on Ricardian and non-Ricardian labor incomes are the same: $\tau_t = \tau_t^o = \tau_t^r$. Consumption differs between the two types of consumers outside the steady state. When making a decision on labor demand, the firm does not distinguish between different workers of type z. Thus, in the aggregate, $N_t^r = N_t^o = N_t$ holds, i.e., they work the same amount of hours. The linearization of equation (13) yields what we call the New Keynesian wage Phillips curve:

$$\pi_t^w = \beta E_t \pi_{t+1}^w - \kappa^w \left[w_t - mrs_t - \chi \hat{\tau}_t \right], \tag{14}$$

where $\pi_t^w \equiv \log(\Pi_t^w / \Pi^w)$, $w_t \equiv \log(\tilde{W}_t / \tilde{W})$, $\hat{\tau}_t \equiv \tau_t - \tau$, $\kappa^w \equiv \frac{\varepsilon_w - 1}{\phi_w}$,[10] and the linearized expression for the marginal rate of substitution is[11]

$$mrs_t = \chi_r (c_t^r - h_r c_{t-1}^r) + \chi_o (c_t^o - h_o c_{t-1}^o) + \varphi n_t, \tag{15}$$

where

$$\chi_r \equiv \sigma \frac{\lambda}{1 - h_r} \frac{(1 - h_o)^{-\sigma}}{\lambda (1 - h_r)^{-\sigma} + (1 - \lambda)(1 - h_o)^{-\sigma}},$$

$$\chi_o \equiv \sigma \frac{1 - \lambda}{1 - h_o} \frac{(1 - h_r)^{-\sigma}}{\lambda (1 - h_r)^{-\sigma} + (1 - \lambda)(1 - h_o)^{-\sigma}}.$$

Note that in case of $h_o = h_r = 0$, equation (15) boils down to the case of constant relative risk aversion (CRRA) utility without habits. Without loss of generality, we postulate, following Furlanetto and Seneca (2012), that $h_r = h_o = h$, implying $\chi_r \equiv \lambda/(1 - h)$ and $\chi_o \equiv (1 - \lambda)/(1 - h)$. The connection between the wage inflation (π_t^w), price inflation (π_t), and the real wage (w_t) can be expressed, in linear form, as

$$\pi_t^w = w_t - w_{t-1} + \pi_t. \tag{16}$$

[10] The slope of the Phillips curve under Calvo wage setting reads $\frac{(1-\xi^w)(1-\beta\xi^w)}{\xi^w} \frac{1}{1+\varphi\varepsilon_w}$, which is equivalent to the slope under Rotemberg wage setting, $\frac{\varepsilon_w - 1}{\phi_w}$. After assigning a value to ξ^w (probability of not resetting the wage), we can calculate ϕ_w.

[11] Note that we assume a tax policy that equates steady-state consumptions across household types (i.e., $C^r = C^o$).

2.4 Fiscal and Monetary Policy

2.4.1 Fiscal Policy

Similarly to Christiano (2011) and Christiano, Eichembaum, and Rebelo (2011), we consider a deterministic experiment: the tax rate is cut by the same amount in each period for the entire duration of the shock.

We operate with two markedly different fiscal scenarios in this paper. The first one assumes a uniform tax cut (lowering labor taxes for both types of households by the same proportion) that is financed by lump-sum taxes levied on Ricardian agents. Hence, non-Ricardians do not pay taxes. In this case the government budget is balanced in each period. This is the simplest possible fiscal scenario that can be built into the model. Therefore, our setup is different from Galí, Lopez-Salidó, and Vallés (2007), where non-Ricardians pay lump-sum taxes.

In the second fiscal scenario, we depart from a balanced budget and assume that a uniform tax cut is financed by government debt that is paid back through labor income taxes that are levied on both types of households.[12] With this latter arrangement, we relax the strong assumption that non-Ricardians do not bear the burden of the tax cut. In the experiments below we assume, in contrast to Galí, Lopez-Salidó, and Vallés (2007), that the steady-state level of debt is not zero. The government budget constraint which implicitly describes the evolution of debt (B) reads as

$$B_t + \tau_t W_t N_t = R_{t-1} B_{t-1} + P_t G_t,$$

which gives way after linearization to

$$b_t + \frac{\tau W N}{Y}\left(w_t + n_t + \frac{1}{\tau}\hat{\tau}_t\right) = \frac{1}{\beta} b_{t-1} + \gamma_b dR_{t-1} - \gamma_b \frac{1}{\beta}\pi_t + g_t,$$

where $b_t \equiv (B_t - B)/Y, dr_t \equiv r_t - r, y_t \equiv (Y_t - Y)/Y, g_t \equiv (G_t - G)/Y$, and γ_b is the government debt-to-GDP ratio. $\hat{\tau}_t$ and dR_t are defined above. For the rest of the paper we set $g_t = 0, \forall t$. When the steady-state debt-to-GDP ratio is positive ($\gamma_b > 0$), the real interest rate

[12]Only Ricardians are entitled to profit income, as they are the owners of the firms.

$(dR_{t-1} - \frac{1}{\beta}\pi_t)$ has an effect on the dynamics of the debt. In particular, a rise in the real interest rate increases debt when $\gamma_b > 0$.

We propose a government revenue rule that is similar to the one in Leeper (1991):

$$\tau_t W_t N_t = \delta_0 + \delta_1 \frac{\tau Y}{B}(B_t - B) + \delta_2 \tau (Y_t - Y) + \varepsilon^\tau, \qquad (17)$$

where $\delta_0 = 0$. As in Leeper (1991), there is no restriction on the values of δ_1 and δ_2. One usually refers to $\delta_2 > 0 (\delta_2 < 0)$ as procyclical (countercyclical) fiscal policy. Here we simply set $\delta_2 = 0$ so that public debt does not fluctuate along the business cycle. We depart from the specification in equation (17) in the sense that we consider the deviation of real government debt from its steady-state value relative to the steady-state of GDP, i.e., $b_t \equiv (B_t - B)/Y$. Exogenous shocks to the tax revenue are captured by ε^τ.

The latter revenue rule can be linearized to yield

$$\hat{\tau}_t = \delta_1 \frac{Y}{WN} b_t - \tau(w_t + n_t) + \{d\varepsilon^\tau\}_{t=\text{zlb start}}^{T=\text{zlb end}},$$

where $X = \{N, W, Y, \tau\}$ is the steady-state value of variable X and $d\varepsilon^\tau \equiv \varepsilon_t^\tau - \varepsilon^\tau = -0.1$ is the deterministic "tax cut shock" (a 10-percentage-points reduction) that is on for the duration of the zero-lower-bound period. "zlb start" and "zlb end" refer to the start and end dates, respectively, of the zero-lower-bound period. We investigate the robustness of our findings by setting different values for δ_1.

2.4.2 *Monetary Policy*

Monetary policy is described by the rule in Christiano, Eichenbaum, and Rebelo (2011):

$$R_t = \max(Z_t, 0), \qquad (18)$$

where

$$Z_t = (1/\beta)(\Pi_t)^{\phi_1(1-\rho_R)}(Y_t/Y)^{\phi_2(1-\rho_R)}[\beta R_{t-1}]^{\rho_R} - 1, \qquad (19)$$

where Z_t is the shadow nominal interest rate which can take on negative values as well. As usual, we assume that $\phi_1 > 1$, $\phi_2 \in [0, 1)$, and $0 < \rho_R < 1$. ϕ_1 controls how strongly monetary policy reacts to changes in inflation, while ϕ_2 governs the strength of the response of nominal interest to changes in output gap.[13] The main implication of the rule in equation (18) is that whenever the nominal interest rate becomes negative, the monetary policy sets it equal to zero; otherwise, it is set by the Taylor rule specified in equation (19). The parameter ρ_R measures how quickly monetary policy reacts to changes in inflation and output gap. Furthermore, inflation in steady state is assumed to be zero, which implies that steady-state net nominal interest rate is $1/\beta$.

The monetary policy rule above can be written, in linear form, as

$$dR_t = \begin{cases} dZ_t, & dZ_t \geq -\left(\frac{1}{\beta} - 1\right), \quad \text{“zero bound not binding”} \\ -\left(\frac{1}{\beta} - 1\right), & \text{otherwise}, \quad \text{“zero bound binding”} \end{cases}$$

$$dZ_t = \rho_R dR_{t-1} + (1 - \rho_R)\frac{1}{\beta}\left[\phi_1 \pi_t + \phi_2 y_t\right].$$

Hence, the ZLB on the nominal interest binds when $dR_t = -\left(\frac{1}{\beta} - 1\right)$. Otherwise, we set $dR_t = dZ_t$.

2.5 Aggregation, Market Clearing, and Equilibrium

The aggregate consumption is a composite of those of the two types of households:

$$C_t = \lambda C_t^r + (1 - \lambda)C_t^o. \tag{20}$$

The aggregate dividend payments are determined by $D_t = (1-\lambda)D_t^o$. The presence of unions implies that both types of households work the same number of hours and, thus, $N_t^r = N_t^o = N_t$ for all t.

It follows that equation (20) can be written in linear form as

$$c_t = \lambda c_t^r + (1 - \lambda)c_t^o, \tag{21}$$

[13]Precisely, the term Y_t/Y does not stand for the output gap, as the definition of the output gap contains the deviation of the actual GDP from its flexible-price level equivalent. Here we simply use the deviation of output from its steady-state value.

which is obtained by setting steady-state consumption and hours worked of each type equal in steady state ($C^r = C^o$) using a lump-sum tax appearing in the budget constraint of Ricardian households.

The goods market clearing is

$$Y_t = C_t + G_t,$$

which can be expressed in linear form as

$$y_t = \gamma_c c_t + g_t, \tag{22}$$

where for the rest of the paper we set $g_t \equiv (G_t - G)/Y = 0$ and $\gamma_c \equiv C/Y$ is calculated as $\gamma_c = 1 - \gamma_g$ with $\gamma_g \equiv G/Y$. After having laid out the building blocks, we are ready to define equilibrium of this model.

DEFINITION 1. *The equilibrium is characterized by a sequence of endogenous quantities,* $\{N_t, C_t^o, C_t^r, C_t, Y_t\}_{t=0}^{\infty}$*; price sequences,* $\{\Pi_t, \Pi_t^w, W_t, R_t, Z_t, \tau_t\}_{t=0}^{\infty}$*; a given set of exogenous deterministic shocks,* $\{\beta_t, \epsilon_t^\tau\}_{t=0}^{\infty}$*; and initial values for debt that satisfy equilibrium conditions of the household, firms, unions, government, and monetary authority such that markets clear, the transversality conditions for the endogenous states are imposed, and the aggregate resource constraint is also satisfied.*

3. Parameterization

3.1 Households

The discount factor, β, is equal to 0.99, implying an annual real interest rate of 4 percent. The intertemporal elasticity of substitution (IES), σ, is set to one, implying log utility, which is a usual choice in the literature. Recently, Christiano, Trabandt, and Walentin (2010) argued that unitary Frisch elasticity is the most reasonable choice that is in line with both macro and micro evidence, so we select $\varphi = 1$. Similar to Christiano (2011), we set $\varepsilon_p = \varepsilon_w = 6$. For the habit formation parameter, h, Furlanetto and Seneca (2012) set a high value of 0.85, while Smets and Wouters (2007) employ a model with various frictions estimate a value of 0.6. Therefore, we consider a value in the middle range and set $h = 0.7$. The steady-state government spending-to-GDP ratio, γ_g, is set to 0.2, mimicking the post-war U.S. evidence. This implies a steady-state consumption-to-GDP ratio, γ_c, of 0.8. Furlanetto and Seneca (2009) calibrate the share of rule-of-thumb consumers (λ) to be between 29 percent and 35 percent after reviewing a couple of econometric studies. Based on this, we set $\lambda = 0.3$, which we think is more plausible empirically than the 0.5 used by Galí, Lopez-Salidó, and Vallés (2007). Parameterization is shown in table 1.

3.2 Fiscal and Monetary Policy

The steady-state quarterly debt-to-output ratio (B/Y) is 2.4, assuming that the yearly debt-to-output ratio is 60 percent. The steady-state labor tax rate (τ) in the model with a balanced budget is chosen to be 30 percent as in Christiano (2011), while it is 26.91 percent in the model with endogenous debt and pinned down by the discount factor, the debt-to-output ratio, and government spending-to-output ratio. In response to the discount factor shock, r_t falls to –0.01, which is close to the mode estimate (–0.0104) by Denes and Eggertsson (2009) using a model that contains only price rigidity and a specific labor market. The duration of the negative demand shock is ten periods,[14] which is in accordance with the modal estimate of Denes and Eggertsson (2009). The inflation coefficient in the Taylor rule, ϕ_1, is 1.5. Following Christiano (2011) and Christiano, Eichenbaum, and Rebelo (2011), there is neither interest rate smoothing ($\rho_R = 0$) nor a response to the output gap in the Taylor rule ($\phi_2 = 0$).

3.3 Firms

The mean posterior estimates of Smets and Wouters (2007) for the Calvo parameters, $\xi^p = 0.66$ ($\xi^w = 0.7$), imply an average price (wage) stickiness of around two (three) quarters. The reduced-form estimates (see Furlanetto and Seneca 2009 for references) on the

[14]Denes and Eggertsson (2009) and Eggertsson (2011) consider a stochastic experiment with a persistence estimate of $\mu = 0.9030$ for the discount factor shock process. This μ is easily translated into our deterministic experiment, knowing that the average duration of this AR(1) is $1/(1-\rho)$ which is roughly 10. For a similar argument, see appendix C of Carlstrom, Fuerst, and Paustian (2012).

Table 1. Parameterization for the Model Used in Experiment 4a except when Indicated Otherwise

Notation	Meaning	Value
	Households	
β	Discount factor	0.99
$1/\sigma$	Intertemporal elasticity of substitution (IES)	1
$1/\varphi$	Frisch elasticity	1
h	Habit formation	0.7
λ	Share of non-Ricardian households	0.3
γ_g	Government spending-to-GDP ratio	0.2
$\tau^{\text{out of ZLB}}$	Steady-state tax rate (experiments 1–3)	30%
$\tau^{\text{out of ZLB}}$	Steady-state tax rate	26.91%
r^{ZLB}	Interest rate at the zero lower bound	−0.0104
	Firms and Unions	
$\xi^p(\xi^w)$	Calvo parameter of price (wage) rigidity	0.66 (0.7)
ε_p	Elasticity of substitution between intermediary products	6
ε_w	Elasticity of substitution between labor types	6
ϵ	Kimball curvature (only experiment 1)	24.77
ϕ_w	Implied by β, ξ^w, ε_w, and φ	266.02
κ	Implied by β and ξ^p	0.1786
κ	Implied by β, ξ^p, and ϵ (only experiment 1)	0.03
	Fiscal and Monetary Authority	
B/Y	Debt-to-GDP ratio (in annual terms)	60%
δ_0	Intercept in the fiscal rule	0
δ_1	Coefficient on debt-to-GDP ratio in the fiscal rule	0.02
δ_2	Coefficient on output gap in the fiscal rule	0
ϕ_1	Response to price/wage inflation in the Taylor rule	1.5
ϕ_2	Response to output gap in the Taylor rule	0
ρ	Interest rate smoothing in the Taylor rule	0

Note: $\tau^{\text{out of ZLB}}$ refers to the tax rate out of the zero-lower-bound state.

New Keynesian price Phillips curve imply $\kappa = 0.03$. Without real rigidity, such a value of κ would imply a very long period of price inertia ($\xi^p = 0.85$). In our baseline calibration without real rigidity (i.e., $\mathcal{I} = 0$), $\xi^p = 0.66$ implies $\kappa = .1786$. When $\mathcal{I} = 1$, the calibration of $\kappa = 0.03$ is achieved by setting an appropriate value for ϵ. The implied value of ϵ is 24.77, which is in the range of empirical estimates listed in Furlanetto and Seneca (2009).

4. Results

4.1 Experiment 1—Only Price Rigidity

Our experiments are in the spirit of Christiano (2011) and Christiano, Eichenbaum, and Rebelo (2011),[15] who assumed that the discount factor shock and the corresponding fiscal policy shock is on for a deterministic period of time. A discount factor shock (alternatively, savings or negative demand shock) hits the economy in period 1. The model is in deterministic steady state until $t = 1$. At $t = 1$ the discount rate drops from its steady-state value of 0.01 (per quarter) to $r = -0.01$ and remains low for $T = 10$ quarters.[16] From quarter 11 ($T+1$) on, the discount rate is back to its steady-state value. Note that all deterministic experiments below assume that the discount factor shock is on for ten periods. The deterministic simulations are executed using a standard shooting algorithm to handle the ZLB problem. The details of this algorithm are available in the appendix of Christiano (2011).[17] Briefly, the algorithm can be described as

[15]Note that sections 2 and 3 of Christiano, Eichenbaum, and Rebelo (2011) consider a stochastic experiment similar to those in Eggertsson (2011) and Woodford (2011), while sections 4 and 5 consider deterministic experiments that are accomplished by using a standard shooting algorithm. In the case of only price rigidity (or only wage rigidity), the system can be rewritten using the Eggertsson and Woodford (2003) type of methodology applicable if the system contains no state variable. The latter is not true in the case of the inclusion of both price and wage stickiness when one of the variables (potentially the real wage) becomes an endogenous state. Hence, we make use of the shooting algorithm of Christiano (2011).

[16]For comparison, Christiano (2011) considered a shock of similar size although a somewhat longer period ($T = 15$).

[17]In particular, we made use of some of the codes of Christiano (2011) and Christiano, Eichenbaum, and Rebelo (2011). The codes are available at Lawrence Christiano's website.

follows. Let t_1 and t_2 denote the guess values for dates of the start and the end, respectively, of the zero-lower-bound period, such that $1 \leq t_1 \leq t_2 \leq T$. Then taxes are decreased for period $t \in [t_1, t_2]$. Next check whether the zero lower bound binds for $t \in [t_1, t_2]$. If not, revise the guess for t_1 and t_2.

The steady-state level of labor tax in the model with a balanced government budget is 30 percent ($\tau = 0.3$). In the no-policy-response simulation, the labor tax rate is at its steady-state level for the entire simulation. In the alternative simulation (denoted with dashed line), the labor tax rate is decreased (in contrast to Christiano 2011 and Christiano, Eichenbaum, and Rebelo 2011, who considered a rise in the tax rate) to 20 percent for the time period in which the zero lower bound on the nominal interest rate is binding. The shooting algorithm determines endogenously the date at which the zero lower bound becomes binding and the date at which the zero lower bound ceases to bind. Thus we have at least two regimes. One of them is with a fixed interest rate (the zero-lower-bound period) and the other one is with a Taylor rule. In general there can be many regimes with either a fixed interest rate or with a Taylor rule operating. It is well known that there is indeterminacy in the New Keynesian model when the interest rate is fixed (see, e.g., Woodford 2011). However, inclusion of the Taylor rule in one of the regimes guarantees determinacy in the other regimes characterized by a fixed interest rate (see, e.g., Carlstrom, Fuerst, and Paustian 2012). We conduct four experiments, and elements of the models used in each experiment are listed in table 2.

Figure 1 shows experiment 1, featuring a model that includes two types of households and only price rigidity. In experiment 1 we assume that there is no wage rigidity in the economy (i.e., the wage Phillips curve in equation (14) is removed—equivalently, ξ^w is set close to zero). Therefore, wages are flexible in experiment 1.[18] For

[18]In this experiment we found numerically that there are two solutions to the shooting problem (hence no unique solution). Also we realized that the drop in output and inflation is extremely large in this simplest variant of the model (without habits and wage rigidity) containing two types of households. To avoid the non-uniqueness problem and to reduce the extreme negative impact of the shock, we introduce strategic complementarity into price setting in the way discussed above. In models containing wage rigidity (experiments 2–4) we do not encounter such non-uniqueness problem.

Table 2. Details of the Models Used in Experiments 1–4

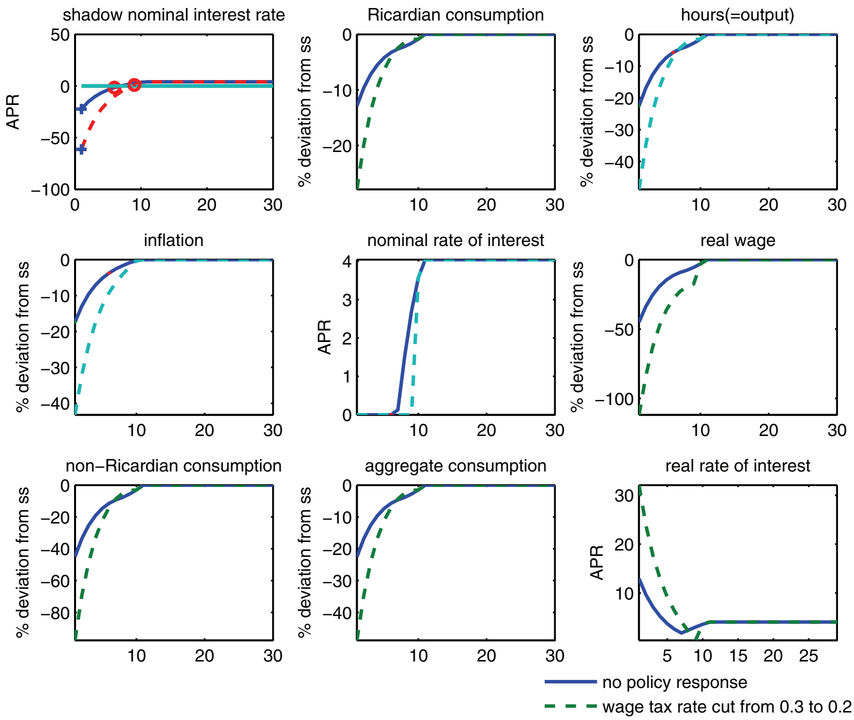
	Features of the Model Used
Experiment 1	Price rigidity
Experiment 2	Price and wage rigidity
Experiment 3	Price and wage rigidity, consumption habits
Experiment 4a	Price and wage rigidity, consumption habits, and government debt with $\delta_1 = 0.02$
Experiment 4b	See experiment 4a with $\delta_1 = 0.9$

Notes: All experiments contain both Ricardian and non-Ricardian households. Experiments 1, 2, and 3 assume a uniform tax cut that is financed by lump-sum taxes levied on Ricardian agents. Experiment 4a–b assume that the uniform tax cut is financed by government debt that is retired through income tax revenue collected from both types of household either in the short run (δ_1 is close to one) or in the long run (δ_1 is close to zero).

simplicity we also abstract from habit formation by setting $h = 0$ in experiment 1. The ZLB becomes binding in period 1 (denoted with + signs on the plot of the shadow nominal interest rate). In the absence of tax policy, the ZLB ends in period 6, while the presence of tax policy makes the ZLB bind for nine periods (denoted with circles). *One can observe that each of the variables except for nominal and real interest rates decline due to the negative demand shock in each experiment and, therefore, the question is always whether the tax cut is able to mitigate the negative effects of the demand shock or not.*

In experiment 1 consumption of non-Ricardians in the case of a decrease in labor taxes falls substantially more than without policy intervention. Therefore, the labor tax cut does not help alleviate the negative consequences of the demand shock (huge deflation and fall in output). Also note that the drop in real wage—which equals the marginal cost due to constant-returns-to-scale assumption—is considerable with or without a change in policy. When the zero lower bound ceases to bind, the Taylor rule becomes operational and monetary policy reacts to positive inflation emerging from expansionary fiscal policy (i.e., the labor tax cut) by raising the nominal interest rate. Thus, there is a large upward movement in the nominal interest rate following the zero-lower-bound period (see figure 1).

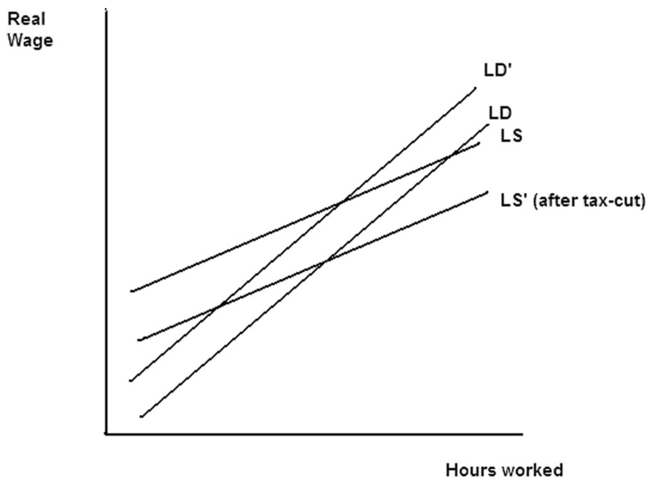
Figure 1. Experiment 1: Model that Includes Two Types of Households and Only Price Rigidity



Notes: The + signs indicate the date at which the zero lower bound on the nominal interest rate becomes binding, and circles appear on the date at which the zero lower bound ceases to bind. Consumption (both Ricardian and non-Ricardian), hours, output, real wage, price inflation, and wage inflation are expressed as a percentage deviation from their steady-state values (on the graphs it is indicated as "% deviation from ss") while the shadow, nominal, and real interest rates are expressed as annual percentage rate (APR). There are two shocks in this experiment: (i) strong negative demand shock with size that equals –0.01 in each period for ten quarters, which leads to a huge fall in all variables, and (ii) a labor tax cut of size –0.1 in each quarter during the zero-lower-bound period which does not necessarily last as long as the negative demand shock.

Similarly, the real interest rate jumps during the zero-lower-bound period because the nominal interest rate is fixed and there is huge deflation due to the negative demand shock. The real interest rate rises even more with a tax cut that is associated with a more

Figure 2. Labor Demand and Supply at the Zero Lower Bound Using the Stochastic Two-State Version of the Model in Experiment 1



pronounced fall in real wages and, hence, a bigger drop in inflation through the New Keynesian Phillips curve.

To provide intuition for experiment 1, let us study the labor market of the model. The effects of the tax cut are depicted in figure 2. The following proposition uses a simple two-state version of the model in experiment 1 with stochastic exit from the zero lower bound and establishes that the labor demand, which is steeper than the labor supply, has a positive slope.

PROPOSITION 1. *Both labor demand and supply are upward sloping at the zero lower bound such that the labor demand is steeper than the labor supply.*

Proof. See the proof in online appendix A.

The workings of the model with non-Ricardians is very similar to the model with only Ricardians in the absence of wage rigidity. The discount factor shock induces households to save more, which they cannot do without capital in equilibrium. The drop in real wage and hours worked, and the corresponding fall in aggregate consumption, ensures that savings are zero in equilibrium. Also importantly, with flexible wages the tax cut ($-\chi\hat{\tau}_t > 0$) is not strong enough to counteract the decline in real wages and hours worked due to the negative demand shock, so the disposable income of non-Ricardians' cannot rise.[19]

The labor supply shifts to the right from LS to LS' due to a decrease in the tax rate (see again figure 2), leading to a drop in wages and hours worked along labor demand, LD. Firms produce less due to the drop in aggregate demand shifting labor demand to the left from LD to LD'. For labor demand that is positively sloped at the zero lower bound, the rightward shift of the LS is contractionary such that hours worked finally drops even more with tax cut relative to the case of no policy intervention. The downward movement in the real wage directly translates to a fall in inflation through the New Keynesian Phillips curve.

In sum, the tax cut magnifies the deflationary effects described by Eggertsson (2011): *price deflation and the contraction in hours worked are more severe with the tax cut even after the inclusion of non-Ricardian households in the absence of wage rigidity.*

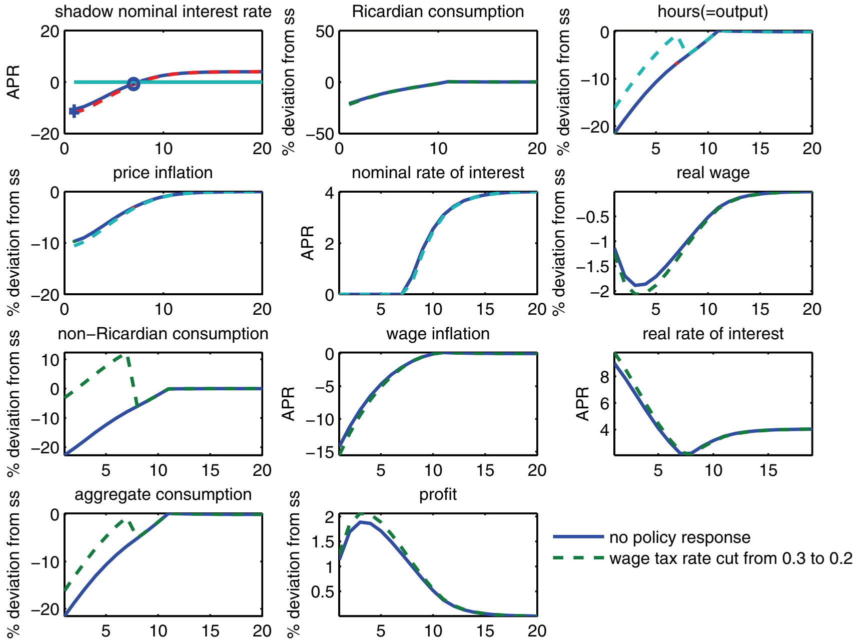
4.2 Experiment 2—Price and Wage Rigidity

Figure 3 shows an experiment similar to the first one, but this time we introduce wage stickiness into the model (experiment 2). The discount rate is set to −0.01 per quarter. The ZLB binds for period 1–6 with or without policy. Wages are set by unions and are assumed to remain fixed for about three quarters. The wage tax cut increases the disposable income of ROT households who consume it. *Again, the rise in the consumption of ROT households (and similarly for the other variables) in response to a labor tax cut should be read as the consumption of ROT households (and also other variables) falls less in the case of the tax cut than without the policy (see figure 3).*

Real wage does not fall dramatically due to the presence of wage stickiness, in sharp contrast to the previous experiment (the absence

[19] Based on the budget constraint of non-Ricardians (see equation (7)), c_t^r drops due to the fall in n_t and w_t, which are not neutralized by $-\chi\hat{\tau}_t^r > 0$.

Figure 3. Experiment 2: Wage Stickiness Introduced into the Model



Notes: The model used in experiment 1 is extended with wage rigidity. The + signs indicate the date at which the zero lower bound on the nominal interest rate becomes binding, and circles appear on the date at which the zero lower bound ceases to bind. "ss" means steady state. There are two shocks in this experiment: (i) a strong negative demand shock with size that equals –0.01 in each period for ten quarters, leading to a huge fall in all variables, and (ii) a labor tax cut of size –0.1 in each quarter during the zero-lower-bound period which does not necessarily last as long as the negative demand shock.

of wage rigidity). But, still, the tax cut remains deflationary (labor supply shifts slightly more to the right than labor demand) and real wage in the case of tax policy falls more than without policy. Observing the graph, we can also see that the wage deflation is higher than the price deflation, implying a fall in the real wage rate. With perfect wage stickiness (ξ^w is close to one)—which is not the case here but serves as a useful abstraction (see, e.g., the argument of Christiano 2011)—the labor supply would remain intact. Next we analyze the indirect reaction of labor demand to the tax cut.

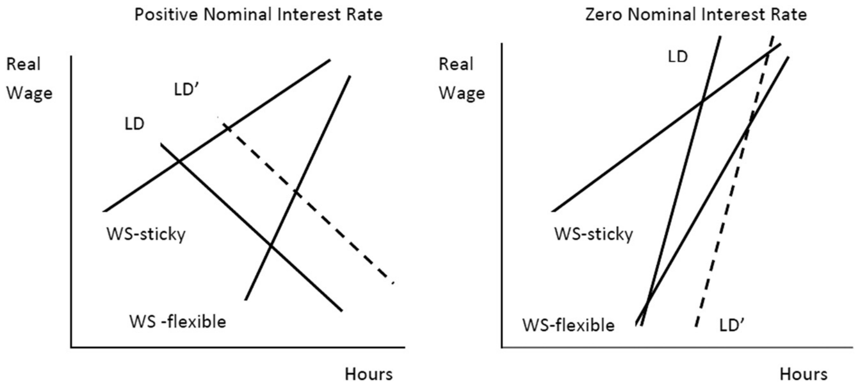
The higher consumption demand of non-Ricardian agents induces many of the firms which cannot charge a higher price due to price stickiness to increase their production. To produce more, firms demand more labor, i.e., the labor demand shifts out. As is well known, in sticky-price models a rise in aggregate demand—due to the higher consumption expenditures of ROT households—leads to a fall in the markup, which induces an outward shift in the labor demand. Below we discuss the reaction of labor supply following the tax cut.

On the one hand, the labor tax cut raises the pre-tax real wage, creating an incentive for the union to increase the labor supply (substitution effect). On the other hand, the labor tax cut has a strong negative wealth effect: Ricardians know that the present tax cut will be offset by higher lump-sum taxes in the future and, therefore, they decrease their demand for consumption and leisure. As the time frame is normalized to one, the fall in leisure implies spending more time working, i.e., Ricardians supply more labor. Due to unions, non-Ricardians work the same number of hours as Ricardians. Thus, both Ricardians and non-Ricardians satisfy higher labor demand by working more. In figure 3 the pre-tax real wage falls more for the tax cut scenario relative to the case of no policy change. Also, we observe that hours worked increases—i.e., it decreases less—with a tax cut. It follows that the labor supply must have increased more than the labor demand.

It also needs to be emphasized that wage stickiness implies that the labor supply (or wage schedule, WS) curve is flatter with rigid relative to flexible wages (Ascari, Colciago, and Rossi 2011) and the outward shift of labor demand in response to higher consumption expenditures of non-Ricardians is associated with more movement in hours worked (a drop) rather than real wage (a rise), which is apparent in figure 4.

The profit in figure 3 rises either with or without a tax cut. It is easy to show algebraically that this is always the case. In first-order log-linear terms, profit can be written as $profit_t = y_t - w_t - n_t$. Because of the constant-returns-to-scale assumption, $y_t = n_t$ and, therefore, $profit_t = -w_t$. The real wage always drops due to the negative demand shock, so it follows that profit has to increase. Profit income that accrues only to Ricardians has an important role in the model. It helps Ricardian consumers who are the owners of the firms

Figure 4. Comparison of Labor Markets under Positive and Zero Nominal Interest Rate



Notes: "WS-sticky" stands for the wage schedule under sticky wages, while "WS-flexible" means the wage schedule under flexible wages.
Source: The left-hand-side figure is a reproduction of Ascari, Colciago, and Rossi (2011, p. 12) while the right-hand-side one is based on figure 4 of Eggertsson (2011, p. 15).

to insulate themselves from the negative wealth effects of the future tax increases and also from the rise in the real interest rate that discourages them from further consumption in the present. Thus, profit income enables Ricardians to avoid larger cuts in consumption due to the future tax burden and the higher real rates.

4.2.1 Some Robustness Checks

The robustness of the finding in experiment 2 is examined in two ways. A detailed description and discussion of these experiments is available in online appendix B. We summarize the most important findings here. First, we examine what happens when the monetary authority follows strict inflation-targeting policy outside the ZLB. It is known that strict inflation targeting is the optimal policy in the basic closed-economy New Keynesian model (see, e.g., Woodford 2003).

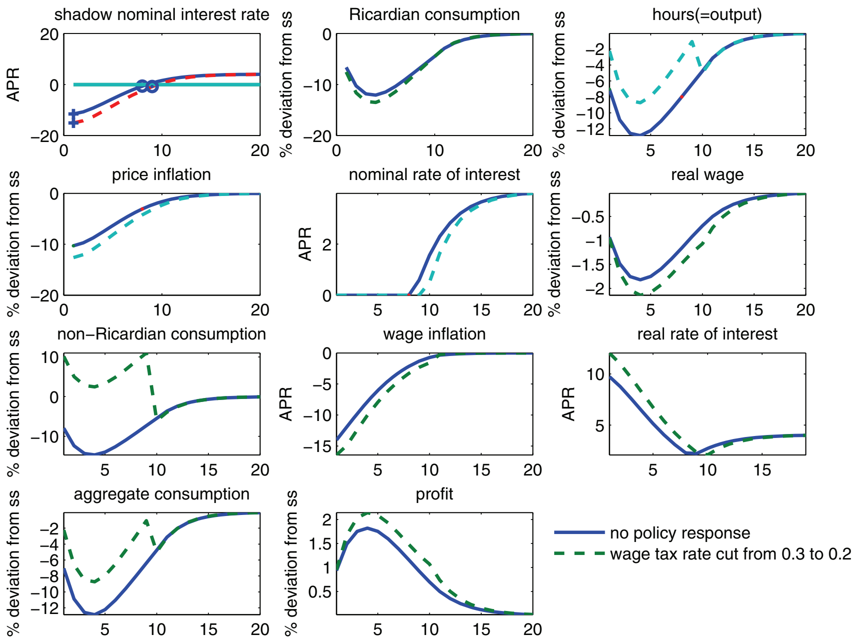
With strict inflation targeting, the Ricardian household expects the real interest rate to be very high after the ZLB period, and therefore it delays its savings to finance the tax cut for the period that is governed by the interest rate rule. Hence, there is scope for Ricardian consumption to decline less with the tax cut relative to the case of no policy intervention during the ZLB period with strict inflation targeting. Indeed, we observe that the real interest rate falls below its long-run level in the second half of the ZLB period, stimulating Ricardian consumption, and makes the stimulatory effect of the tax cut even more powerful. The extra boost from consumption makes it possible for the output not to fall below its steady state in the case of the tax cut in the second half of the ZLB period.

Second, we ask what is the impact of extending the labor tax cut beyond the ZLB period? We find that the extension of the tax cut until, for instance, period 15 has small additional stimulatory effects because the positive effects of the tax cut are weakened by the Taylor rule which is in operation outside the ZLB period.

4.3 Experiment 3—Price Rigidity, Wage Rigidity, and Consumption Habits

Experiment 3, which is shown in figure 5, makes use of the model in the previous simulation, but now it includes external habit formation in consumption as well. Due to the lagged consumption term, habit formation injects some endogenous persistence into the model and leads to hump-shaped impulse responses in consumption and hours. Habit formation is a well-known feature of middle-sized DSGE models, such as the one of Smets and Wouters (2007), and is found useful in matching the empirical VAR evidence. Also, habit formation is usually regarded as having some solid psychological foundation. The presence of habits mitigates the effects of the negative demand shock. This can be explained as follows. As argued above, it is the rise in the real interest rate that makes people delay their consumption expenditure. The introduction of habits reduces the sensitivity of consumption to changes in the real interest rate (this can be quickly verified by looking at equation (5), where the coefficient on the interest is smaller in the case of habits $[\frac{1-h_o}{1+h_o}\frac{\beta}{\sigma}]$ than it is for the standard CRRA case $[\beta/\sigma]$). The ZLB binds from period 1 to 8 (9) without (with) policy. Still output (hours) declines less when labor tax cut policy is applied.

Figure 5. Experiment 3: Model with External Habit Formation in Consumption

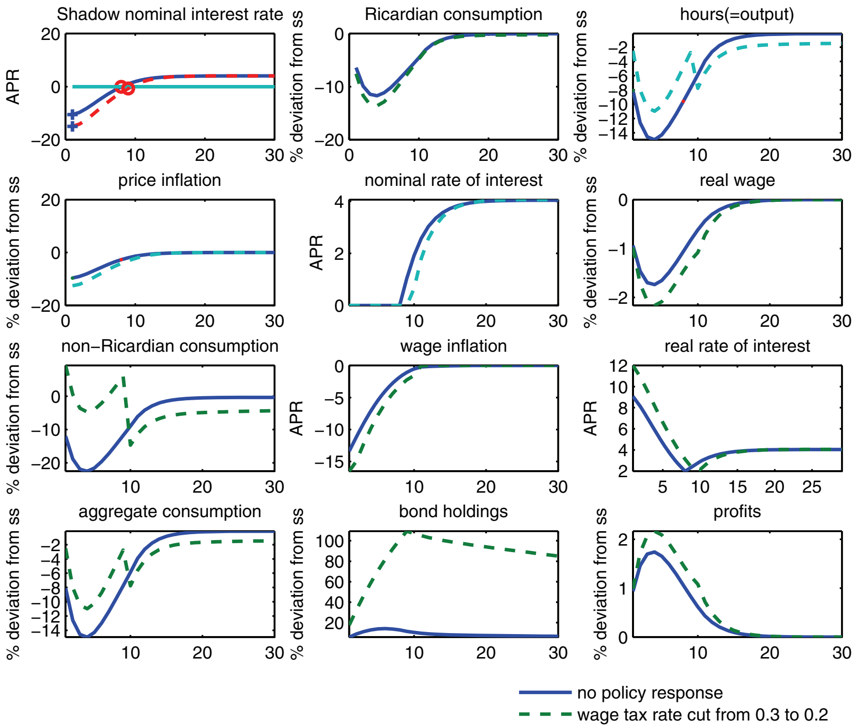


4.4 Experiment 4—Price Rigidity, Wage Rigidity, Consumption Habits, and Government Debt

In experiment 4 we assume more realistically that the tax cut is financed by government debt which is retired through an increase in labor tax revenue either in the short or long run. We allow for inherited debt from the past: that is, the steady-state debt-to-output ratio is positive, and interest payments on current debt affect the evolution of future debt. In previous experiments, only the Ricardians bear the burden of the tax cut. However, now, it is also the non-Ricardians who have to take part in settling the bill. Taxation is uniform: both types of households pay the same tax rate.

The parameter choice for δ_1 in the fiscal rule (equation (17)) turns out to be crucial for the outcome. When δ_1 is low, the tax cut is mainly financed with debt which is paid back in the distant

Figure 6. Experiment 4a: $\delta_1 = 0.02$



future (see, for instance, the impulse responses with $\delta_1 = 0.02$ in figure 6, where bond holdings refer to real debt). This case lends support for tax cut policy and is in accordance with the findings of Bilbiie, Monacelli, and Perotti (2012, 2013), who argue in favor of a (lump-sum) tax cut[20] as follows. When debt repayment happens far in the future, a uniform tax cut is pure redistribution (transfer) from Ricardians to non-Ricardians in the present, while it is a

[20]In this chapter we found that intuition in the case of a labor tax cut is similar to the lump-sum tax cut discussed by Bilbiie, Monacelli, and Perotti (2012), who assume the consolidation of debt in the form of higher lump-sum taxes. In this chapter, however, consolidation of debt is carried out through increases in labor taxes which distort the consumption-leisure trade-off, discourage from work, and depress output even more beyond the zero-lower-bound period.

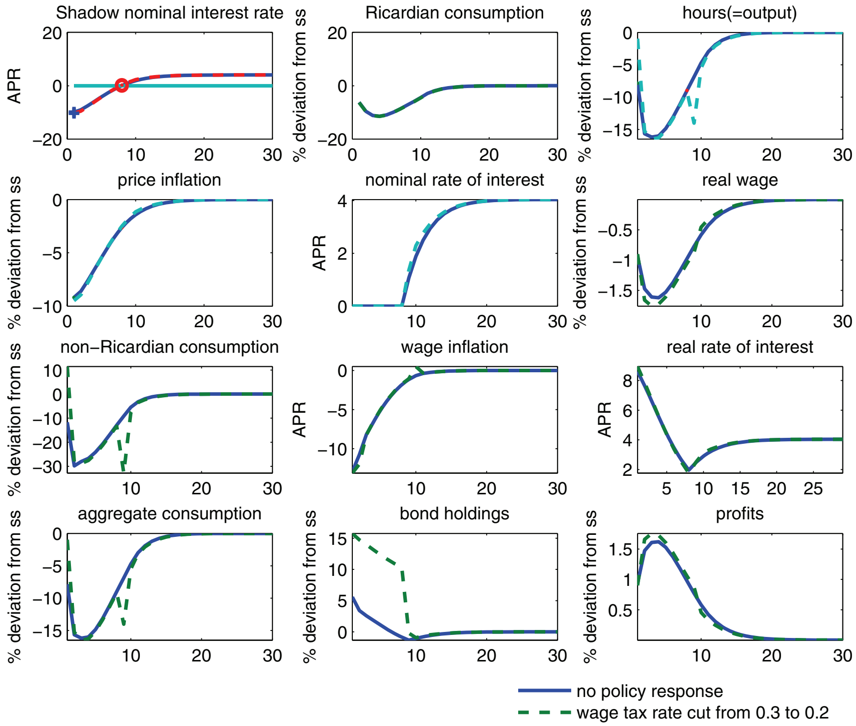
transfer from non-Ricardians to Ricardians in the future. The evolution of Ricardian consumption is totally consistent with our story. Ricardians pay attention to changes in their whole lifetime income (the present discounted value of income), which remains unaltered with temporary changes in taxes (see the straight and dashed lines overlap in figure 6).

Thus, the outcome of the policy in the case of endogenous debt with low δ_1 is very similar to the first fiscal scenario in which only Ricardians pay for the tax cut through lump-sum taxes. In particular, Ricardians do not react to the policy, while non-Ricardians enjoy the tax decrease, as it is not offset in the present by a rise in the labor tax. Also note that this tax cut policy leads to better outcome only in the zero-lower-bound period which coincides with the period of sharp accumulation in debt. As soon as the Taylor rule is operative again (from period 11), this type of tax cut policy is strictly worse—mainly because of its negative effects on the consumption of non-Ricardians. Indeed, from period 11, the tax cut is over and non-Ricardians also have to take part in settling the debt accumulated in the zero-lower-bound period. As a result, non-Ricardian consumption with fiscal policy beyond the zero-lower-bound period is below the one without fiscal policy.

On the contrary, when δ_1 is closer to one (see figure 7 for $\delta_1 = 0.9$), the tax cut in the present is counteracted by a tax rise and there is no rationale for such a policy. This is also confirmed by looking at the evolution of bonds in the same figure. In the first ten periods bond holdings are positive, but from period 11 on they are the same as in the case of no policy. This is markedly different from the previous experiment where the late repayment ensured that bond holdings are positive even beyond period 10 in the case of a tax cut relative to no policy intervention. Values of δ_1 that equal one or above are to be avoided, as they would render the path of debt explosive.

It deserves explanation why we observe a run-up of the debt in the zero-lower-bound period even without fiscal policy (see straight lines for bond holdings in figures 6 and 7). All the figures plot the evolution of real debt. In particular, increases in debt during the zero-lower-bound period (in the absence of fiscal policy) reflect the fact that the real value of debt increases due to deflation.

Figure 7. Experiment 4b: $\delta_1 = 0.9$



5. Robustness

The robustness of the tax cut policy to small changes in the parameters is assessed here. We shortly summarize the results of the robustness checks, which are more detailed in the online appendix C. Our baseline calibration considers unitary IES and Frisch elasticity. We find that the tax cut remains to be stimulative for the IES smaller than one and the Frisch elasticity higher than one (or when either (both) of them is (are) lower than one), which is suggested by empirical papers (see discussion in online appendix C). It turns out that the favorable effects of the tax cut do not survive if the share of non-Ricardians is lowered to 20 percent or the average duration of wage rigidity is reduced from 3.33 to 3 quarters. However, when IES is smaller than one and Frisch elasticity is higher or lower than one—calibrations which we argue are more plausible empirically—the tax cut policy is still better than the lack of policy even for either a lower share of non-Ricardians or a shorter duration of wage/price rigidity. The tax cut policy is also robust to the replacement of price inflation to wage inflation in the Taylor rule.

6. Conclusion

After augmenting the baseline New Keynesian model containing price and wage rigidity with rule-of-thumb (or non-Ricardian) households, we argued that a labor tax cut can partly offset the fall in output and deflation caused by a negative demand shock that made the zero lower bound on the nominal interest rate binding. Importantly, we assumed that we cut the labor tax rate that is levied upon the households and not upon the firms. Under such an arrangement the labor tax cut acts like a traditional fiscal stimulus that raises aggregate demand. We found that the tax cut policy is stimulative if it is financed by lump-sum taxes levied completely on Ricardian agents. We also explored a more realistic scenario when a tax cut is covered by long-term government debt which is settled by both types of households in the form of taxes on labor income. Still, the tax cut is found to have positive effects on output because non-Ricardians who do not take into consideration the future tax burden enjoy the increase in their disposable income by spending more. Finally, rule-of-thumb consumers can be thought of as a shortcut of modeling agents with borrowing constraint. Based on the logic of the model with rule-of-thumb households, our finding should remain valid in a model with savers and borrowers who face borrowing constraints.

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