Long-Run Inflation Uncertainty*

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In this commentary I argue that option price data offer useful insights into the long-run macroeconomic uncertainty perceived by investors. Data on inflation options in the United States show substantial dispersion in the risk-neutral distribution of long-run inflation rates. This may indicate that substantial uncertainty about the inflation target still exists. However, I argue that a high dispersion in the risk-neutral distribution could also reflect disagreement among investors who are confident in their own forecasts and do not necessarily perceive a high degree of subjective uncertainty. Disagreement could potentially reconcile the relative stability of inflation in recent years with the substantial dispersion in the risk-neutral distribution of long-run inflation and in survey forecasts of long inflation.

JEL Codes: E31, E44, G13.

1. Introduction

The topic of the session that I have been asked to comment on is *expectations*. In any evaluation of the *challenges to achieving price stability*—the overall theme of this conference—macroeconomic expectations should play an important role. Decisions of price setters and investors today depend on their forward-looking assessment of the macroeconomic situation. Many instruments in central bankers' toolkits, and forward guidance in particular, work through their effects on the public's expectations. However, macroeconomists' understanding of the formation of expectations is still quite limited, and there is still substantial room for improvement in the

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measurement of expectations. The two papers in this session advance research on these two important fronts.

The paper by Jonathan Wright titled "Options-Implied Probability Density Functions for Real Interest Rates" (this issue) looks at market-based measures of the (risk-neutral) distribution of real interest rates extracted from prices of traded options. Market-based measures offer the promise of a high-frequency assessment of the entire term structure of distributions of future outcomes, although their interpretation is not entirely straightforward due to conflation with risk premia, illiquidity effects, and other confounding factors.

In my commentary, I will focus on long-term inflation expectations—arguably the most important place to look for threats to price stability. And I want to focus on one aspect of the long-run outlook for which market-based measures like those in Wright's paper are particularly useful: subjective uncertainty. Surveys often focus on point forecasts without eliciting the subjective uncertainty of the respondent (the U.S. Survey of Professional Forecasters (SPF) is a notable exception). Option price data are therefore a useful source of information about the uncertainty perceived by investors.

Subjective uncertainty measures can help shed light on a number of important policy questions. One example that I will discuss is anchoring of inflation expectations. The anchoring hypothesis not only makes predictions about the (lack of) reaction of point forecasts to news but also about the (lack of) subjective uncertainty about long-run inflation rates. Data on long-run inflation uncertainty—market-based or otherwise—should therefore be informative about the degree to which monetary authorities succeeded in anchoring expectations.

The issue of subjective uncertainty is also closely related to the issue of expectations heterogeneity. If there is substantial uncertainty about outlook for inflation, people may also disagree about this outlook. For this reason, the article by Boneva et al. titled "The Effect of Unconventional Monetary Policy on Inflation Expectations: Evidence from Firms in the United Kingdom" in this issue performs an important task by providing insight into the expectations formation of firms. The expectations of decision makers in firms are not necessarily identical to those of commonly surveyed households or professional forecasters. The literature on firms' expectations is still

quite small, even though firms, as price setters, play a crucial role in determining the rate of inflation.

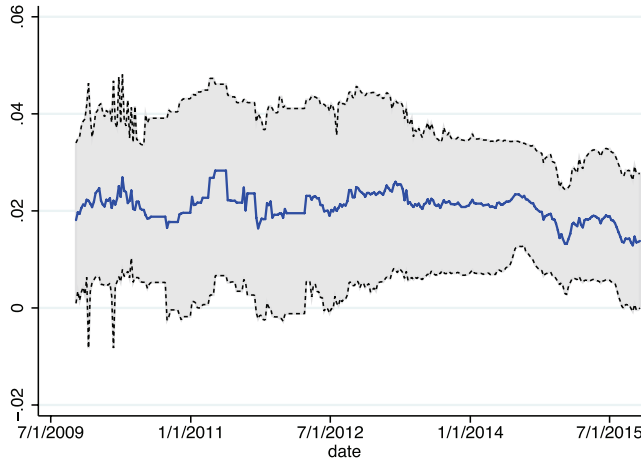
I will argue below that expectations heterogeneity is likely to affect the risk-neutral distribution of outcomes and hence market-based measures of uncertainty. As far as I am aware, this is not an issue that has received a lot of attention in the literature. On the one hand, the fact that market-based measures of uncertainty could be informative about disagreement is another reason to be interested in studying these measures. On the other hand, the potential presence of disagreement effects complicates the interpretation of these measures. The effect of belief dispersion on market-based measures of uncertainty could be particularly relevant in recent years, as unconventional monetary policies have, at least anecdotally, led to a substantial disagreement about the inflation outlook among financial market participants.

2. Market-Based Measures of Long-Run Inflation Uncertainty

For some years now, inflation caps and floors have been traded in the United States. The owner of an inflation cap (floor) receives a payment if the average CPI inflation rate exceeds (is lower than) the strike of the cap (floor). Prices of these derivative instruments can be used to extract market-based measures of investors' beliefs about inflation. Unlike inflation-indexed bond prices or inflation swaps, these option-like derivatives allow the extraction of a whole probability distribution at various horizons. The extracted probability distribution reflects beliefs under the risk-neutral measure, i.e., the probabilities are adjusted for risk premia. For now, I will interpret the probability distribution extracted from long-maturity inflation caps and floors as reflecting investors' perception of long-run inflation uncertainty. I will discuss the effect of risk premia further below.

Figure 1 shows the percentiles of the risk-neutral density of five-year average (annualized) CPI inflation based on data from the Federal Reserve Bank of Minneapolis. The figure presents the median, the 10th percentile, and the 90th percentile of the risk-neutral density. As the figure shows, investors seem to perceive a substantial degree of uncertainty about long-run inflation. In October 2015, the

Figure 1. Percentiles of the Risk-Neutral Density of Five-Year Inflation



Note: The figure shows the 10th percentile, median, and 90th percentile of the risk-neutral distribution of inflation over a five-year horizon extracted from inflation options by the Federal Reserve Bank of Minneapolis.

spread between the 90th and the 10th percentile is about 3 percentage points. This spread has come down a little bit since 2011 when it maxed out at around 4 percentage points, but it is still substantial.

The high degree of dispersion in the risk-neutral distribution of long-run inflation is striking and difficult to reconcile with the view that inflation expectations are well anchored. In the United States, the persistence of inflation has decreased substantially in the past few decades (Williams 2006). Inflation expectations seem to be less sensitive to macroeconomic news in recent years than in earlier decades (Davis 2012). Evidence of this kind has given increasing support to the idea that the Federal Reserve has gained credibility in its intention and ability to keep inflation close to a stable long-run target. Bernanke (2007) expresses this view, for example, albeit with the caveat that the anchoring of expectations is not perfect. Indeed, Gürkaynak et al. (2007) find that prices of nominal and real bonds in the United States still imply some sensitivity of long-run inflation expectations to macroeconomic news.

There are two somewhat separate notions of anchored expectations: (i) insensitivity of inflation expectations to macroeconomic news, including recent surprise inflation; and (ii) a high degree of confidence in the intention and ability of the monetary authority to keep inflation close to a target. It is possible that inflation expectations are anchored in the sense of (i) but that there is nevertheless substantial uncertainty about the long-run target. For illustration, consider the following model of perceived inflation dynamics:

$$\pi_{t+1} = \pi_t^* + \sigma\epsilon_{t+1}, \tag{1}$$

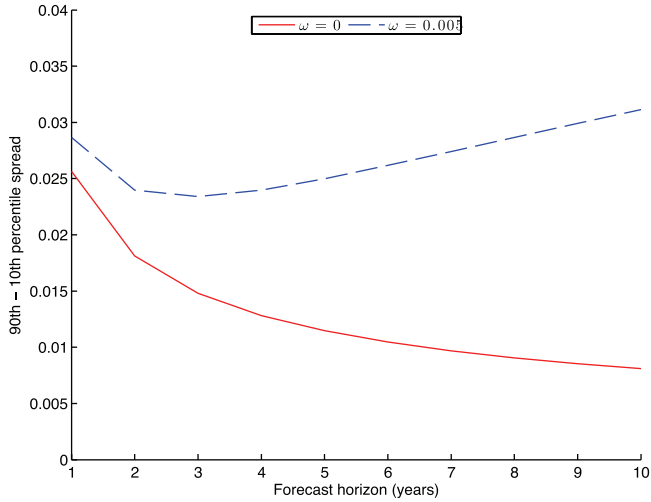
$$\pi_t^* = \pi_{t-1}^* + \omega u_t, \tag{2}$$

where ϵ_t and u_t are uncorrelated standard normal shocks. In this model, ϵ shocks have no effect on inflation expectations. In this sense, expectations are well anchored. However, if $\omega > 0$, there can be considerable uncertainty about the future path of the target π^* and hence long-run inflation rates. The signals u that move the perceived target need not be news associated with regular macroeconomic announcements. In this sense, substantial target uncertainty could very well be consistent with a low sensitivity of inflation expectations to macroeconomic news.

The term structure of uncertainty about inflation should be informative about the relative importance of ϵ and u shocks. Figure 2 shows the forecast uncertainty in terms of the spread between the 90th and 10th percentile of the distribution over various horizons from one to ten years ahead (with $\sigma = 0.01$). The solid line shows that in the absence of target rate uncertainty ($\omega = 0$), there is strong decay of the uncertainty over longer horizons as the ϵ shocks average out. If there is target rate uncertainty ($\omega = 0.005$), the random-walk nature of the perceived target process induces higher uncertainty for inflation rates averaged over longer horizons, which can offset the decrease in the transitory shock uncertainty. Similar implications about long-run inflation uncertainty follow from a more sophisticated unobserved-components stochastic volatility model (Stock and Watson 2010) as estimated in Kitsul and Wright (2013).

Figure 3 plots the 90th–10th percentile spreads from the extracted risk-neutral distribution of inflation for one-year, two-year, and five-year horizons. As the figure shows, there is about as much uncertainty about the five-year inflation rate as there is

Figure 2. Long-Run Inflation Uncertainty with and without Uncertainty about Target



Note: The figure shows the spread between the 90th and 10th percentile of the distribution of inflation rates.

about inflation rates over one-year and two-year horizons. This pattern would be difficult to explain in a model in which the public has little uncertainty about the inflation target. It looks very similar to the target rate uncertainty case in figure 2.

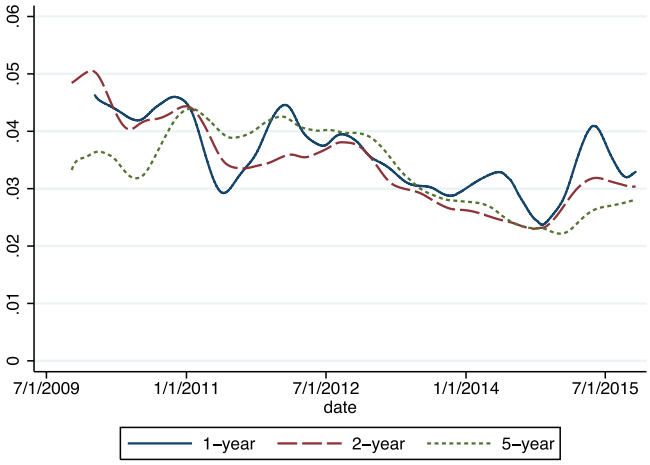
3. Interpreting Dispersion in the Risk-Neutral Distribution

3.1 Lack of Anchoring?

The relatively high degree of dispersion in the risk-neutral distribution of long-run inflation evident in figures 1 and 3 raises questions about the success of the monetary authority in anchoring long-run inflation expectations. Apparently, a substantial degree of uncertainty about long-run inflation still exists.

This evidence is also reason to be somewhat skeptical of explanations that attribute the relative stability of inflation expectations

Figure 3. Interpercentile Range (90th–10th Percentile) of the Risk-Neutral Density of Inflation over Various Horizons



Note: Smoothed with local linear regression and tricube kernel with bandwidth 0.10 (of sample size).

("missing disinflation") in the recent Great Recession to firm anchoring of inflation expectations. If inflation expectations really were so firmly anchored, why would there be so much uncertainty priced into long-maturity inflation options? Clearly, more research is needed on this point, but the evidence suggests that it may be worth looking for alternative explanations. For example, Coibion and Gorodnichenko (2015) show that much of the missing disinflation can be explained by the fact that households' inflation expectations were very sensitive to the rise in oil prices in the years leading up to 2013. This explanation, based on lack of anchoring, would be consistent with the high degree of uncertainty about long-run inflation rates reflected in market-based probabilities. It may also help explain why the median of the risk-neutral distribution of long-run inflation in figure 1 has declined substantially in 2015 coincident with a fall in oil prices.

3.2 Risk Premia?

So far I have treated the percentile spreads of the risk-neutral distribution of inflation as a representation of subjective uncertainty of

financial market participants. Of course, since the risk-neutral probabilities reflect the product of actual probabilities and the stochastic discount factor, the risk-neutral probabilities are affected by risk premia. For example, if financial market participants dislike states of very low and very high inflation and are willing to pay a premium to insure against these states, the risk-neutral probabilities of these tail states will be higher than the actual probabilities. However, while such risk premia can make the risk-neutral distribution more dispersed compared with the actual distribution, it is not obvious that there is a simple risk premium explanation for the fact that the dispersion does not decay with longer horizons. It seems difficult to explain this feature of the data without substantial actual uncertainty about long-run inflation rates.

It is also worth keeping in mind that one could argue, along the lines of Feldman et al. (2015), that policymakers should base their decisions on the risk-neutral distribution. A social-welfare-maximizing policy should take into account not only the subjective probabilities that the public attaches to future states of the world but also the price that the public is willing to pay to insure against these states of the world. Risk-neutral probabilities capture both of these aspects. With regard to long-run inflation, a dispersed risk-neutral distribution indicates some combination of high uncertainty about long-run inflation and a high willingness to pay for high-inflation and deflation insurance. This indicates that the public would value policies—e.g., credible commitment to an inflation target—that reduce the likelihood of reaching these states of the world.

However, in imperfect markets subject to segmentation frictions, illiquidity, and limited participation, the interpretation of risk-neutral probabilities is not straightforward. I illustrate this next by pointing out how investor disagreement could potentially influence the dispersion of the risk-neutral distribution.

3.3 Expectations Heterogeneity?

Discussions of the interpretation of risk-neutral probabilities typically focus on how risk premia, and, occasionally, illiquidity distortions in option prices drive a wedge between actual and risk-neutral probabilities. Interpretation of risk premia is typically based on a

representative-agent framework, where the stochastic discount factor is interpreted as revealing the marginal valuation that households place on resources in different states of the world. However, the risk premia embedded in the risk-neutral distribution, especially in its tails, can also reflect the disagreement between agents about the likelihood of future events rather than their subjective uncertainty. The literature on market-based probabilities has not paid much attention to this possibility.

To see how expectations heterogeneity can affect the risk-neutral distribution, it is easiest to consider a model in which the public can buy options, but only specialized, risk averse, imperfectly hedged intermediaries can sell options. This setup is broadly consistent with the evidence in Gârleanu, Pedersen, and Poteshman (2009) that market makers are net sellers of options in the stock index option market. Applied to the inflation options market, this would mean that prices of inflation caps reflect the beliefs of investors expecting high inflation (while those expecting deflation cannot sell these options) and the price of floors reflects the beliefs of investors expecting deflation. Intermediaries can smooth out some of these effects, but if they are risk averse and cannot perfectly hedge, they will only partly do so. As a consequence, the tail probabilities of the risk-neutral distribution are elevated relative to actual probabilities. In this interpretation, risk premia embedded in risk-neutral probabilities are the manifestation of differences in beliefs. Buraschi and Jiltsov (2006) provide a more sophisticated asset pricing model with disagreement that implies similar effects on the risk-neutral distribution.

For these reasons, it is possible that the relatively high dispersion of the risk-neutral distribution of long-run inflation in figures 1 and 3 reflects disagreement between market participants rather than a high level of subjective uncertainty of market participants in their own assessment of future inflation. Anecdotally, judging by the diversity of opinions that various investors, pundits, and others expressed in reaction to the Federal Reserve's unconventional monetary policy measures, there was plenty of disagreement in recent years. Moreover, research has identified various dimensions of systematic disagreement between individuals. For example, Coibion and Gorodnichenko (2015) highlight differences between professional forecasters and households. Malmendier and Nagel (2016) document disagreement between individuals of different age with different

accumulated inflation experiences. The paper by Boneva et al. in this issue shows that there is disagreement between different types of firms in the United Kingdom.

The view that considerable disagreement about inflation persisted in the wake of the Great Recession in the United States would also be consistent with the evidence in Cecchetti and Hakkio (2009) that adoption of an explicit inflation-targeting regime does not reduce the dispersion of private-sector inflation expectations by much. Since the Federal Reserve has not adopted an explicit inflation target, there is even more reason to expect disagreement about the long-run inflation outlook to persist. Disagreement could potentially offer a common explanation of the facts that inflation rates and the mean or median of professional forecasts were not sensitive to realized inflation rates and macroeconomic news in recent years, but at the same time substantial dispersion in survey forecasts and in the risk-neutral distribution extracted from option prices persisted.

4. Concluding Remarks

To sum up, option price data offer useful insights into the macroeconomic uncertainty perceived by investors. In particular, data on inflation options in the United States indicate that there is substantial dispersion in the risk-neutral distribution of long-run inflation. Even though realized inflation was quite stable in recent years and measures of the central tendency of the perceived inflation distribution did not move much, market participants still seem to perceive uncertainty about the ability and willingness of the Federal Reserve to keep long-run inflation close to a stable target.

However, challenges remain in the interpretation of market-based measures of uncertainty. One issue that seems to deserve more attention of researchers is the role of disagreement in generating the risk premia that are embedded in the risk-neutral distribution of macroeconomic outcomes. Conventional interpretations take a representative-agent approach. But there is reason to believe that the tails of the risk-neutral distribution extracted from option prices could be influenced by disagreement among investors. If so, a high degree of dispersion in the risk-neutral distribution could indicate differences in opinion among investors (who may be quite confident in their own forecasts) rather than high levels of subjective uncertainty.

References

Bernanke, B. S. 2007. "Inflation Expectations and Inflation Forecasting." Speech at NBER Summer Institute Monetary Economics Workshop, Cambridge, MA, July 10. Available at http://www.federalreserve.gov/newsevents/speech/Bernanke20070710a.htm.

Buraschi, A., and A. Jiltsov. 2006. "Model Uncertainty and Option Markets with Heterogeneous Beliefs." *Journal of Finance* 61 (6): 2841–97.

Cecchetti, S. G., and C. Hakkio. 2009. "Inflation Targeting and Private Sector Forecasts." NBER Working Paper No. 15424.

Coibion, O., and Y. Gorodnichenko. 2015. "Is the Phillips Curve Alive and Well after All? Inflation Expectations and the Missing Disinflation." *American Economic Journal: Macroeconomics* 7 (1): 197–232.

Davis, J. S. 2012. "Inflation Expectations Have Become More Anchored Over Time." *Economic Letter* (Federal Reserve Bank of Dallas) 7 (13).

Feldman, R., K. Heinecke, N. Kocherlakota, S. Schulhofer-Wohl, and T. Tallarini. 2015. "Market-Based Probabilities: A Tool for Policymakers." Working Paper, Federal Reserve Bank of Minneapolis.

Gârleanu, N., L. H. Pedersen, and A. M. Poteshman. 2009. "Demand-Based Option Pricing." *Review of Financial Studies* 22 (10): 4259–99.

Gürkaynak, R. S., A. T. Levin, A. N. Marder, and E. T. Swanson. 2007. "Inflation Targeting and the Anchoring of Inflation Expectations in the Western Hemisphere." *Economic Review* (Federal Reserve Bank of San Francisco) 2007: 25–47.

Kitsul, Y., and J. H. Wright. 2013. "The Economics of Options-Implied Inflation Probability Density Functions." *Journal of Financial Economics* 110 (3): 696–711.

Malmendier, U., and S. Nagel. 2016. "Learning from Inflation Experiences." *Quarterly Journal of Economics* 131 (1): 53–87.

Stock, J. H., and M. W. Watson. 2010. "Modeling Inflation After the Crisis." NBER Working Paper No. 16488.

Williams, J. C. 2006. "Inflation Persistence in an Era of Well-Anchored Inflation Expectations." Economic Letter No. 2006-27, Federal Reserve Bank of San Francisco.