

Asymmetric Inflation Expectations, Downward Rigidity of Wages, and Asymmetric Business Cycles*

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Abstract

I show that household expectations of the inflation rate are more sensitive to inflation than to disinflation. To the extent that workers have bargaining power in wage determination, this asymmetry in their beliefs makes wages respond quickly to inflationary forces but sluggishly to deflationary ones. I microfound asymmetric household expectations using ambiguity-aversion: households, who do not know the quality of their information, overweight inflationary news since it reduces their purchasing power, and underweight deflationary news since it increases their purchasing power. I embed asymmetric beliefs into a general equilibrium model and show that, in such a model, monetary policy has asymmetric effects on employment, output, and wage inflation in ways consistent with the data. I show that although wages are downwardly rigid in this environment, optimal monetary policy need not have a bias towards using inflation to grease the wheels of the labor market.

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1 Introduction

Keynesian macroeconomic theory posits that sticky wages are a crucial feature of labor markets. Rigid wages can cause involuntary unemployment, amplify fluctuations in employment at business cycle frequencies, and break monetary neutrality. In recent years, a large number of empirical papers have shown not only that wages are very sticky, but that there is a clear asymmetry in the way that wages are sticky. In particular, wages appear more flexible when they are rising than when they are falling. Examples include Barattieri et al. (2010), Dickens et al. (2007), Daly and Hobijn (2013), as well as the seminal contribution by Bewley (1999). Furthermore, recent work by Kaur (2012) shows that downward nominal rigidities distort labor market outcomes in rural India.

In this paper, I argue that informational frictions for households can help to explain the asymmetric adjustment of wages during the business cycle. This paper makes two main contributions: (1) it documents the existence of a statistically robust asymmetry in how households form their expectations of inflation; in particular, I show that households are much better at anticipating accelerations in the inflation rate than decelerations. In a typical model, this asymmetry in household beliefs feeds into asymmetry in wage-setting where wages respond more vigorously to inflationary forces than disinflationary forces. This makes demand-driven business cycles asymmetric. Positive monetary policy shocks (or more generally positive demand shocks) are highly inflationary but do not increase output by very much, whereas negative monetary policy shocks (or negative demand shocks) are not very disinflationary but cause large unemployment. I show that this asymmetry in beliefs are unique to households and are not present for professional forecasters. (2) I microfound the source of asymmetric belief formation in an equilibrium model where households are ambiguity-averse and are trying to make robust decisions. I show that with this microfoundation, optimal monetary policy is still subject to the Lucas critique, and the central bank does not have a systematic inflationary bias despite the existence of downward rigidities.

The intuition for my microfoundation is simple. When negotiating their wages, workers observe their nominal wages perfectly, but foresee the real cost of the goods and services that they will consume imperfectly. As in Lucas (1973), workers face a signal extraction problem when trying to determine their purchasing power. However, households' signals of the general price level are subject to Knightian uncertainty, since households do not know precisely how informative their signals are. This means that they will be more sensitive to inflationary news than disinflationary news because, for a fixed nominally denominated employment contract, inflationary news lowers their purchasing power whereas disinflationary news raises it (relative to their prior expectations). This asymmetry of beliefs can then show up in wage-setting since distrustful workers will, to the extent that they can, refuse wage cuts in the presence of deflation, but demand wage increases in the presence of inflation.

This distrustful attitude of workers towards the inflation rate is attested to in many surveys. For example, according to Shiller (1997), the "biggest gripe about inflation" expressed by 77% of

the general public is that “inflation hurts my real buying power. It makes me poorer.” Interestingly, only 12% of economists chose this answer.¹ The households’ answer makes sense in partial equilibrium, since over short horizons, households can treat their wages as known and exogenous to the inflation rate.

I embed ambiguity into a general equilibrium model and find that monetary shocks have very asymmetric effects on wage inflation and output. In particular, positive monetary shocks result in high wage inflation and small booms, since households react strongly to the inflationary signals by demanding wage increases. On the other hand, negative monetary shocks cause large unemployment and relatively small disinflation, since households distrust the disinflationary signals and refuse wage cuts. I verify the model’s predictions about the asymmetric impact of monetary policy on output and wage inflation using time series data for the US.

The asymmetry implied by the model substantially alters the welfare costs of business cycles when compared to Lucas (1987). Whereas, in the Lucas model, positive shocks cancel out negative shocks so that the welfare cost of fluctuations is second order, in this model, positive demand shocks do not cancel with negative demand shocks, and stabilization policy reaps first order gains. This harks back to the point made by De Long and Summers (1988) that demand stabilization may fill in the troughs without shaving the peaks. In a paper about external devaluation, Schmitt-Grohé and Uribe (2011) have also recently drawn attention to this point. I also investigate optimal monetary policy in my model. The received wisdom in the literature, following Akerlof et al. (1996), is that if wages are downwardly rigid, then central banks should have an inflationary bias to “grease the wheels” of the labor market. This way real wage cuts can be masked by a positive inflation rate. Unfortunately, in my model, inflationary biases from the central bank are not helpful since household expectations adjust to take them into account. Any inflationary bias built into central bank policies are undone by endogenously-formed household expectations. In other words, the model predicts an asymmetric equilibrium, but the central bank is powerless to do anything about the asymmetry.

Other theoretical treatments of downwardly rigid wages often take the rigidity as given and investigate its consequences (e.g. Daly and Hobijn (2013); Schmitt-Grohé and Uribe (2011); Kaur (2012); Akerlof et al. (1996); Hall (2005)). These models are usually motivated by an exogenous fairness norm, and assumptions about the function relating wages to worker effort. Akerlof (1982) is a seminal paper in this strand of the literature. Other attempts to microfound downward wage rigidity are based on implicit contracts, where firms insure their workers against fluctuations by uncoupling the real wage from marginal product of labor; a leading example is Holmstrom (1983), but this literature is focused on real wages and does not bring inflation into the analysis. The theory I propose not only explains downward rigidity at the micro level, it also has novel macro implications. The model predicts that monetary policy has asymmetric effects on output and wage

¹Instead, the most popular reason given by economists was, “inflation makes it hard to compare prices, forces me to hold too much cash, and is inconvenient.” Only 7% of households chose this answer.

inflation. There is already evidence that monetary policy has asymmetric effects on output, for example in De Long and Summers (1988), Cover (1992), and Angrist et al. (2013). I present new evidence that monetary policy also has asymmetric effects on wage inflation consistent with the model’s prediction.

The model of Knightian uncertainty I use is the one axiomatized by Gilboa and Schmeidler (1989). In this framework, workers have multiple priors about the information content of their signals, and they act according to their worst-case prior when making decisions. A similar modelling device is used by Epstein and Schneider (2008) in the context of asset pricing to model skewness in asset returns. Kuhnen (2012) finds empirical evidence in support of asymmetric learning in the context of financial markets, where agents are overly pessimistic in the loss region. Another recent paper that incorporates ambiguity aversion into a macroeconomic model is by Ilut and Schneider (2012). However, my results differ markedly from theirs both in terms of the research question and the set up of the model.²

The outline of this paper is as follows. In section 2, I set out a basic partial equilibrium model with ambiguity aversion that demonstrates my mechanism. In section 3, I endogenize prices and output, and study the effects of monetary shocks on real and nominal variables. In section 4, I present empirical evidence in favor of asymmetric adjustment of beliefs, and time series evidence that wage inflation responds asymmetrically to positive and negative monetary shocks as predicted by the model. I also discuss the extent to which the model can explain the cross-sectional distribution of wage-changes. In section 5, I investigate a simple optimal policy problem and compute the welfare cost of business cycles. In section 6, I embed my mechanism into a standard New Keynesian model with sticky wages, and draw out some of its implications. I find that time-varying Knightian uncertainty can act like a cost-push shock in the economy, creating a tradeoff between inflation and output stabilization for the central bank even though there are no supply shocks in the model. I summarize and conclude in section 7.

2 Partial Equilibrium Model

Consider the following partial equilibrium model that establishes the intuition for the rest of the paper. Suppose that there is an employer and a worker. The worker has log utility in his real wage, is endowed with a unit of labor, and an exogenous outside option d (I take this to be the utility of leisure). In other words, his preferences are given by

$$u(w_t/p_t, x_t) = \log(w_t/p_t)\mathbf{1}(x_t = 1) + d\mathbf{1}(x_t = 0),$$

²Ilut and Schneider (2012) are interested in how ambiguity about the level of productivity affects an economy, whereas I am interested in how ambiguity about the informativeness of price signals affect wage setting.

where x_t is a binary variable for whether or not he works, w_t is the nominal wage, p_t is the price level in period t and d is an exogenous outside option. The employer makes a nominal wage offer w_t to the worker, who then chooses whether or not to work. If the worker does not work, he receives the exogenous outside option d .

The worker chooses to work if

$$E_t \left(\log \left(\frac{w_t}{p_t} \right) \right) \geq d,$$

where the expectation is taken with respect to the worker's information set. Since the nominal wage is always known with certainty, we can rearrange this expression to get that the lowest wage for which the worker will work is

$$w_t = \exp(d + E_t(\log(p_t))). \quad (1)$$

Suppose that workers receive a public signal s_t about the inflation rate. Then we can rewrite (1) as

$$\log(w_t) = d + \log(p_{t-1}) + E(\log(\pi_t)|s_t),$$

where π_t is the inflation rate from period $t - 1$ to t and workers are assumed to know the price level in the previous period. This equation makes clear that the wage inherits the properties of the conditional expectation function when viewed as a function of the signal s_t . If households' expectations of inflation are, for some reason, asymmetric (they rise more quickly than they fall), then the wage will also behave asymmetrically with respect to inflationary pressures.

The basic mechanism of the model in this paper is that households place greater weight on inflationary news than disinflationary news. To motivate this assumption, we can look for evidence of this asymmetry by using inflation expectation surveys of households. I use the Michigan survey of inflation expectations. Denote inflation in period t by π_t and median household inflation expectations of inflation 12 months ahead by $\hat{\pi}_{t+12|t}$.³ In figure 1, expected revisions to the inflation rate $\hat{\pi}_{t+12|t} - \pi_t$ are plotted against actual changes to the inflation rate $\pi_{t+12} - \pi_t$. As expected, we see a steep convexity, indicating that the median household's expectations of inflation are more responsive to positive rather than negative changes to inflation. This finding is a direct confirmation of the model's underlying mechanism.

In figure 2, we see that the median forecasts made by professional forecasters do not exhibit this convexity. This suggests that source of the asymmetry, at least in the United States, is in how households process information, rather than in the information itself. Furthermore, the fact that there is an asymmetry in the beliefs of households is unique to this model and would not be found in preference-based theories that rely on loss-aversion or fairness norms. This empirical finding is in the same spirit as the experimental results of Fehr and Tyran (2001) who emphasize that subjects

³I use the median, rather than the mean, forecast since it is less sensitive to the existence of extreme outliers in survey responses.

respond weakly to deflationary shocks and strongly to inflationary shocks, although my results are about accelerations and decelerations in the inflation rate.

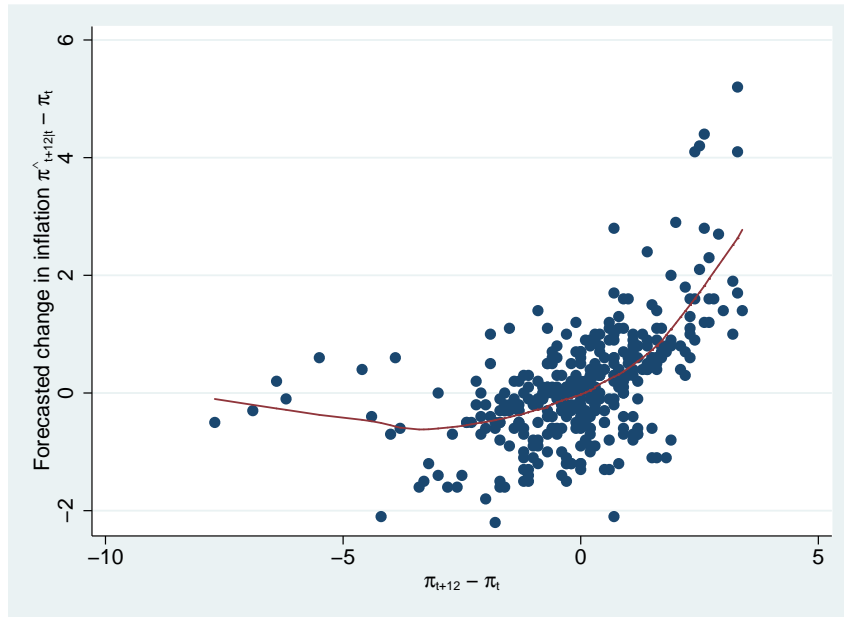


Figure 1: Forecast revisions of the annual inflation rate by the median household in the Michigan Survey of Inflation Expectations from 1983-2012, plotted against realized changes in the annual inflation rate as measured by the CPI.

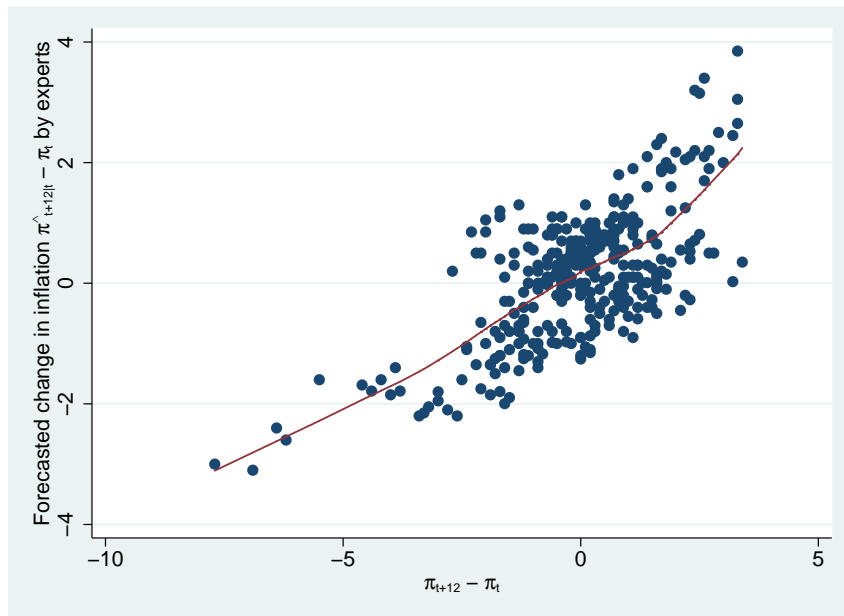


Figure 2: Forecast revisions by the median professional forecaster in the Michigan Survey of Inflation Expectations from 1983-2012, plotted against realized changes in the annual inflation rate as measured by the CPI.

To demonstrate how ambiguity-aversion can deliver convex conditional expectations, suppose that the price level p_t is given by

$$\log(p_t) = \mu + \varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}(0, \sigma^2),$$

and both the worker and the employer know μ . Let s_t be a noisy public signal of the price shock ε_t ,

$$s_t = \varepsilon_t + \varepsilon_s, \quad \varepsilon_s \sim \mathcal{N}(0, \sigma_s^2).$$

Note that

$$\varepsilon_t | s_t, \mu, \sigma^2, \sigma_s^2 \sim \mathcal{N}\left(\frac{\sigma^2}{\sigma^2 + \sigma_s^2} s_t, \frac{\sigma_s^2 \sigma^2}{\sigma^2 + \sigma_s^2}\right).$$

This means we can rewrite the work condition (1) as

$$w_t \geq \exp\left(d + \mu + \frac{\sigma^2}{\sigma^2 + \sigma_s^2} s_t\right).$$

Now Suppose that there is ambiguity about how informative the signal s_t is. That is, the signal-to-total variance ratio $\frac{\sigma^2}{\sigma^2 + \sigma_s^2}$ is unknown. For example, suppose that the worker knows only that $\sigma_s \in [\underline{\sigma}_s, \bar{\sigma}_s]$. Gilboa and Schmeidler (1989) have axiomatized and provided a representation theorem for the preferences of such agents. In particular, such agents follow a minmax procedure, where they make decisions that maximize their worst-case expected utility. In other words, when information quality is ambiguous, expression (1) becomes

$$\begin{aligned} w_t &= \max_{\sigma_s \in [\underline{\sigma}_s, \bar{\sigma}_s]} \exp(d + \mu + E(\log(p_t) | s_t)) \\ &= \exp\left(d + \mu + \max_{\sigma_s} E(\log(p_t) | s_t)\right) = \exp\left(d + \mu + \tilde{E}(\log(p_t) | s_t)\right). \end{aligned} \quad (2)$$

For notational convenience, I denote the expectations taken with respect to the worst-case prior by \tilde{E} . Maximizing worst-case expected outcomes in this way is very similar to the ‘‘Robustness’’ framework proposed by Hansen and Sargent (2011). The specific information structure I use is similar to the one posited by Epstein and Schneider (2008), who use it to study skewness in asset prices.

In this section, the source and nature of the ambiguity is not important. It could be due to Knightian uncertainty about official statistics, or a reduced form representation of the fact that consumers have idiosyncratic consumption baskets and there is ambiguity about the extent to which official statistics are relevant to one’s individual consumption basket. Alternatively, we could assume that there is ambiguity about σ^2 to capture Knightian uncertainty about demand shocks. A third interpretation is that households are playing a game against the statistical agency in the country, and political pressures on the statistical agency result in the public signals being

less informative in the presence of inflation than disinflation. We will return to these issues later, for now, let us take (2) as given.

Expression (2) implies that $\sigma_s = \underline{\sigma}_s$ when $s_t \geq 0$, and $\sigma_s = \bar{\sigma}_s$ when $s_t < 0$. In figure 3, we see an asymmetry in the adjustment of wages to signals of the price level. In particular, wages increase much more rapidly in response to inflationary signals than they fall in response to disinflationary signals. Similar results obtain for the more general constant-relative-risk-aversion utility case, and in the case with ambiguity in the variance of the monetary shock σ instead of ambiguity in the variance of the noise term σ_s .

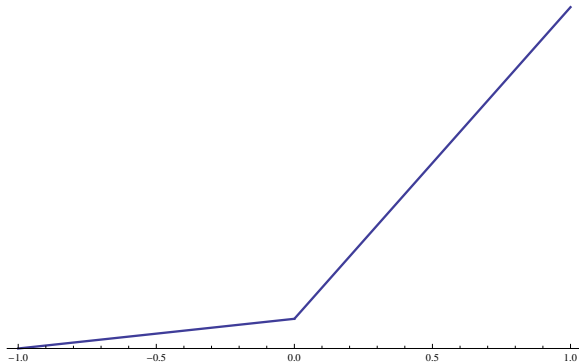


Figure 3: Critical wage as a function of s .

The intuition for this result is that households take inflationary news very seriously, since the worst case scenario is that bad news is very informative. On the other hand, households distrust or ignore disinflationary news, since the worst case scenario is that good news is uninformative.

3 A simple general equilibrium model

So far, I have used a partial equilibrium model to draw out the implications of asymmetric expectations and ambiguity for the individual workers and employers. In this section, I show that the insights of the previous section survive in general equilibrium with endogenous prices and output.

Consider a two period model with a representative firm and a continuum of identical households. In period 1, nature sets money supply M , and there is a noisy public signal s of M . The firm posts a nominal wage W conditional on the signal, and households decide whether or not to apply for a job. In period 2, M becomes common knowledge, the firm chooses the fraction of the population it wishes to employ, and workers spend the money supply on consuming the output. Intuitively, in period 2, nominal wages are fixed, but the price level changes; this proxies a world where nominal wages are fixed over the length of a contract while prices continue to change.

In period 1, following our earlier discussion, the firm sets the wage to equate the utility of working with the outside option

$$\tilde{E}(u(C)|s) = d, \tag{3}$$

where C is consumption of workers when employed and d is the exogenous outside option in utility terms. Let households have log utility so that the wage, in period 1, is given by

$$\tilde{E}(u(C)|s) = \tilde{E}(\log(C)|s) = \tilde{E}(\log(W/P)|s) = d. \quad (4)$$

This makes the households indifferent between working and consuming their outside option. Rearrange this for the wage to get

$$\log(W) = d + \tilde{E}(\log(P)|s). \quad (5)$$

In period 2, the stock of money is revealed, the firm sets marginal product of labor equal to the real wage

$$f'(L) = \frac{W}{P}. \quad (6)$$

To give a role to money, suppose that households have a cash-in-advance constraint, so that their total expenditures have to equal the money supply

$$PC = M. \quad (7)$$

Market clearing for the consumption good implies that

$$C = f(L).$$

Let the firm's production technology be given by

$$f(L) = L^\alpha, \quad \alpha \in (0, 1),$$

then the firm's first order condition (6) implies that

$$f(L) = L^\alpha = \left(\frac{W}{\alpha P} \right)^{\frac{\alpha}{\alpha-1}}.$$

Combine this with market clearing, and (7) to get

$$\frac{M}{P} = C = L^\alpha = \left(\frac{W}{\alpha P} \right)^{\frac{\alpha}{\alpha-1}}. \quad (8)$$

Rearrange this to get

$$P = \frac{M^{1-\alpha} W^\alpha}{\alpha^\alpha}, \quad (9)$$

so the equilibrium price is a geometric average of the money stock and the wage. Substitute this

expression for P into the wage setting equation (5) to get

$$\log(W) = \frac{d}{1-\alpha} + \tilde{\mathbb{E}}(\log M|s) - \frac{\alpha}{1-\alpha} \log(\alpha) \quad (10)$$

as the wage in equilibrium. To get equilibrium output, substitute the equilibrium price (9) into (7) to get

$$C = \frac{M}{P} = \frac{\alpha^\alpha M}{M^{1-\alpha} W^\alpha} = \left(\frac{\alpha M}{W}\right)^\alpha.$$

Finally, equilibrium labor is given by using the production function $L^\alpha = C$ to get

$$L = \alpha \frac{M}{W}. \quad (11)$$

Equations (10) and (11) show that if, for whatever reason, conditional expectations of the money shock as a function of the signal are more convex than the signal is as a function of the money shock, we should observe asymmetries in wage-setting and in employment fluctuations. As before, ambiguity aversion towards the underlying shocks to the money supply can deliver the asymmetric conditional expectation function seen in figure 1. Suppose that s is a normal noisy signal of the shock to $\log(M)$. Denoting logs in lower case letters,

$$m|s \sim \mathcal{N}\left(\mu + \frac{\sigma^2}{\sigma^2 + \sigma_s^2} s, \frac{\sigma^2 \sigma_s^2}{\sigma^2 + \sigma_s^2}\right).$$

Denote the signal-to-total variance ratio $\frac{\sigma^2}{\sigma^2 + \sigma_s^2}$ by ψ , and note that $\psi \in [\underline{\psi}, \bar{\psi}]$. Then the equilibrium wage (10) is

$$w = \frac{d}{1-\alpha} + \mu + \bar{\psi} s \mathbf{1}(s \geq 0) + \underline{\psi} s \mathbf{1}(s < 0) - \frac{\alpha}{1-\alpha} \log(\alpha),$$

and equilibrium employment (11) is

$$l = \frac{1}{1-\alpha} \log(\alpha) + m - \frac{d}{1-\alpha} - \mu - \bar{\psi} s \mathbf{1}(s \geq 0) - \underline{\psi} s \mathbf{1}(s < 0). \quad (12)$$

In the benchmark case of full information, $\underline{\psi} = \bar{\psi} = 1$, employment is independent of monetary shocks and the wage is a linear function of the size of the monetary shock. This corresponds to the neoclassical case without frictions. In the case with no ambiguity, $0 \leq \underline{\psi} = \bar{\psi} < 1$, the nominal wage and the level of employment are linear in monetary shocks. The intuition here is the same as for the Lucas (1973) islands model. In the case with ambiguity, $0 \leq \underline{\psi} < \bar{\psi} \leq 1$, shown in figure 4, we have asymmetric nominal wage adjustment and employment fluctuations in response to monetary shocks. So we recover the intuition from the partial equilibrium model in section 2, but with additional predictions about the level of employment and the effects of monetary policy (both of which were absent in the partial equilibrium model).

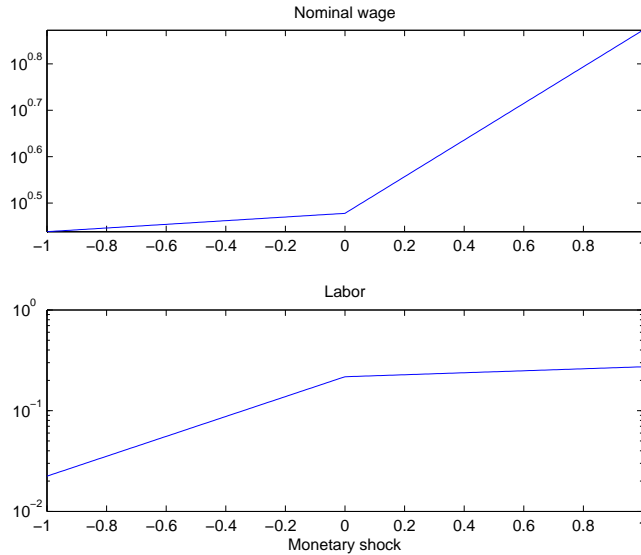


Figure 4: The nominal wage and employment as a function of shocks to money supply.

4 Empirical Evidence

In this section, we look at the extent to which this stylized model is consistent with patterns found in the data. I present three types of evidence: (1) direct evidence of asymmetry in household beliefs towards inflation; (2) time-series evidence from the United States relating wage and price inflation to monetary shocks; (3) evidence from the cross-sectional distribution of wage changes in different countries and different time periods;

4.1 Evidence on Asymmetric Expectations

The basic mechanism of the model is that households place greater weight on inflationary news than disinflationary news. We can try to test for this mechanism directly by using inflation expectation surveys of households. Technically, the expectations of the agents in the model are not unique, since they have multiple priors. So, I assume that individuals report their “worst-case” or “effective” beliefs in surveys – these are the beliefs that would rationalize their behavior if they were Bayesians.

I use the Michigan survey of inflation expectations. Denote inflation in period t by π_t and median household inflation expectations of inflation 12 months ahead by $\hat{\pi}_{t+12|t}$. As mentioned previously, figure 1 plots expected revisions to the inflation rate $\hat{\pi}_{t+12|t} - \pi_t$ against actual changes to the inflation rate $\pi_{t+12} - \pi_t$. As expected, we see a kink at zero, indicating that the median household’s expectations of inflation are more responsive to positive rather than negative changes to inflation. The asymmetry is a direct confirmation of the model’s underlying mechanism. A placebo test, plotted in figure 2, shows that the median forecasts made by professional forecasters

do not exhibit a kink or convexity.

A regression version of these graphs will allow us to control for covariates and do a formal hypothesis test of the existence of the kink in the conditional expectation function generated by ambiguity-aversion. To that end, consider the following reduced-model for household inflation expectations

$$\hat{\pi}_{t+12|t} = c_0 + c_1 \hat{\pi}_{t+11|t-1} + c_2 s_t \mathbf{1}(s_t \geq 0) + c_3 s_t \mathbf{1}(s_t \leq 0) + c_4 \pi_{t-1} + \varepsilon_t.$$

So, the median household's expectations of future inflation are a linear function of the median household's expectations last month, the value of inflation last month, which reflects the publicly available information in period t , and a piecewise linear function of the signal. In table 1, I proxy for the signal received by the households by using the realized change in the inflation rate. In other words, I set

$$s_t = \pi_{t+12} - \pi_t.$$

The results of this regression are reported in table 1. In both specifications, we can reject the null hypothesis that $c_2 = c_3$ at the 1% significance level. All of the results on beliefs are entirely robust to controlling for the demographic characteristics of the respondents, namely, their age group (18-34, 35-54, 55+), their region (West, North Central, North East, South), their gender, their income group (bottom tertile, middle tertile, top tertile), and their education level (high school or less, some college, college).

In table 1, I proxy for the signal received by households using the realized change in the inflation rate. Therefore, my estimates suffer from attenuation bias, since the realized change is an imperfect measure of the signal received by the household. An alternative approach is to suppose that the signal received by households and professional forecasters is the same. After all, the information used by professional forecasters is mostly publicly available. Denote the forecasts of headline inflation 12 months ahead made in period t by $\pi_{t+12|t}^e$. I use the change in inflation predicted by professional forecasters

$$expert_t^+ = (\pi_{t+12|t}^e - \pi_t) \mathbf{1}(\pi_{t+12|t}^e - \pi_t \geq 0), \quad expert_t^- = (\pi_{t+12|t}^e - \pi_t) \mathbf{1}(\pi_{t+12|t}^e - \pi_t < 0)$$

as my measure for the signal received by households. To the extent that this is a better measure of the signal received by households (say the signal received by households is literally the median forecast), then this regression should suffer from less attenuation bias. The results of this test are reported in table 2. As before, we can reject the hypothesis that positive and negative news are treated symmetrically at the 5% or 1% significance level depending on the specification. The general lesson we learn from these results is that in the US, households are much better at anticipating accelerations in the inflation rate than decelerations.

Since the supporting data is from after the Great moderation, one may question the extent

Table 1: Responsiveness of Household Inflation Forecasts to Positive and Negative Shocks

	(1)	(2)
	$\hat{\pi}_{t+12 t}$	$\hat{\pi}_{t+12 t}$
$\hat{\pi}_{t+11 t-1}$	0.957*** (0.02)	0.716*** (0.06)
$(\pi_{t+12} - \pi_t)\mathbf{1}(\pi_{t+12} - \pi_t \geq 0)$	0.062** (0.03)	0.131*** (0.03)
$(\pi_{t+12} - \pi_t)\mathbf{1}(\pi_{t+12} - \pi_t < 0)$	-0.019 (0.02)	-0.001 (0.03)
π_{t-1}		0.164*** (0.04)
Constant	0.100* (0.06)	0.317*** (0.08)
Observations	407	407

Newey-West t statistics in parentheses with lag parameter 4.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Columns regress median 12-months ahead inflation expectations of households on realized positive and negative changes to the actual headline CPI inflation rate and other covariates. The inflation expectation data comes from the Michigan Survey of Consumers and the inflation data comes from the BLS. The question households are responding to in the Michigan survey is “During the next 12 months, do you think that prices in general will go up, or go down, or stay where they are now? By what percent do you expect prices to go up, on the average, during the next 12 months?” Column (1) and Column (2) are the same except that column (2) controls for the lagged inflation rate. In both specifications, the coefficient on positive changes to the inflation rate have larger magnitude than the one for negative changes in the inflation rate at the 1% significance level. Hats indicate forecasts, and subscripts indicate time periods. The sample period is monthly data from January 1978 to December 2012. Observations are at the month level.

Table 2: Responsiveness of Household Inflation Forecasts to Professional Forecasts

	(1)	(2)	(3)
	$\hat{\pi}_{t+12 t}$	$\hat{\pi}_{t+12 t}$	$\hat{\pi}_{t+12 t}$
π_t	0.430*** (0.03)	0.261*** (0.05)	0.113** (0.04)
$expert_t^+$	0.312*** (0.08)	0.270*** (0.08)	0.098** (0.04)
$expert_t^-$	-0.002*** (0.00)	-0.002*** (0.00)	-0.001*** (0.00)
π_{t-1}		0.164*** (0.05)	0.057 (0.05)
$\hat{\pi}_{t+11 t-1}$			0.565*** (0.06)
Constant	1.686*** (0.11)	1.719*** (0.10)	0.797*** (0.12)
Observations	415	414	414

Newey-West t statistics in parentheses with lag parameter 4.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Columns regress median 12-months ahead inflation expectations of households on positive and negative changes to the inflation rate forecasted by the median professional forecaster and other covariates. The inflation expectation data for households and experts comes from the Michigan Survey of Consumers and the inflation data comes from the BLS. The question households are responding to in the Michigan survey is “During the next 12 months, do you think that prices in general will go up, or go down, or stay where they are now? By what percent do you expect prices to go up, on the average, during the next 12 months?” All columns control for the actual inflation rate. Column (2) also controls for the lagged inflation rate, and Column (3) controls for the lagged inflation rate and the lagged median household inflation forecast. For column (1) and (2) we can reject the hypothesis that the coefficient on $expert^+$ and $expert^-$ are the same at the 1% significance level, and for column (3) we can reject this hypothesis at the 5% significance level. Hats indicate forecasts, subscripts indicate time periods. The sample period is from January 1978 to December 2012. Observations are at the month level.

to which such asymmetries can persist in countries with high (but stable) inflation rates. Using household expectations data from Argentina, I verify that that higher average inflation does not appear to affect the existence of the asymmetry. To this end, I run the same regression with data from Argentina and present the results in table 3. As predicted by the theory, the point estimate for c_2 is much larger than for c_3 . Since we have many fewer observations, the parameters are imprecisely estimated, and we cannot reject the hypothesis that the coefficients are the same. The inflation data used here are from a private consulting firm and are not official figures from the government (which are widely known to be unreliable).

Further supportive evidence of asymmetry is found in the working paper by Cavallo et al. (2013). They perform a randomized controlled experiment on Argentinean households and find that household expectations respond more (almost five times more strongly) to inflationary news than disinflationary news. This asymmetry disappears if instead of news about the inflation rate, households are given news about the change in the price of a specific set of goods. This indicates that the source of ambiguity might be in how aggregate statistics relate to one's individual consumption basket, rather than the conduct of monetary policy or the source of the information.

4.2 Evidence from aggregate time-series

Next, we look at time series evidence of the relationship between wage inflation, price inflation, and monetary policy shocks. The model implies that wage inflation should respond more strongly to positive monetary shocks than negative ones. To test this, I use a measure of structural monetary shocks from Coibion and Gorodnichenko (2012). Following Romer and Romer (2004), I estimate the following reduced form model

$$\pi_t^w = a_0 + \sum_{j=1}^J a_j \pi_{t-j}^w + \sum_{k=0}^K b_k \varepsilon_{t-k}^+ + \sum_{l=0}^L c_l \varepsilon_{t-l}^- + \nu_t,$$

where π_t^w is annual wage inflation, ε_t^+ and ε_t^- are positive and negative monetary shocks, and ν_t is the error term. The measure of wage inflation is the seasonally adjusted annual percent change of average hourly earnings of production and nonsupervisory employees for the total private sector taken from Federal Reserve Economic Database.

We can then test the hypothesis that

$$\sum_{k=0}^K b_k + \sum_{l=0}^L c_l = 0,$$

or that the cumulative effect of a positive shock on wage inflation is the same as the cumulative effect of a negative shock. I use the BIC to select the autoregressive lag length J , although the results are robust to changing the number of lags to be higher (for example, the results are virtually

Table 3: Responsiveness of Household Inflation Expectations to Positive and Negative Shocks in Argentina

	(1)	(2)
	$\hat{\pi}_{t t}$	$\hat{\pi}_{t t}$
$\hat{\pi}_{t-1 t-1}$	0.778*** (0.07)	0.911*** (0.04)
π_{t-1}	0.195* (0.08)	
$(\pi_t - \pi_{t-1})\mathbf{1}(\pi_t - \pi_{t-1} \geq 0)$	0.909* (0.37)	1.015** (0.38)
$(\pi_t - \pi_{t-1})\mathbf{1}(\pi_t - \pi_{t-1} < 0)$	0.365 (0.62)	0.185 (0.60)
Constant	0.910 (1.01)	1.843 (1.08)
Observations	79	79

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Columns regress median contemporaneous inflation expectations of households on positive and negative changes to the inflation rate as measured by a private consulting company. The inflation expectation data and the inflation data were kindly shared by Cavallo et al. (2014). Both columns control for the lagged expected inflation rate. Column (2) also controls for the lagged inflation rate. The hypothesis that the coefficients for positive and negative changes are equal in magnitude cannot be rejected. Hats indicate forecasts, subscripts indicate time periods. The sample period is from August 2006 to March 2013. Observations are at the month level.

Table 4: Responsiveness of Wage Inflation to Monetary Policy Shocks

	(1)	(2)	(3)
	π_t^w	π_t^w	π_t^w
ε_t^+	0.234*** (0.08)	0.202*** (0.07)	0.201*** (0.07)
ε_t^-	-0.110* (0.06)	-0.076 (0.06)	-0.081 (0.07)
ε_{t1}^+		0.132* (0.08)	0.126* (0.07)
ε_{t-1}^-			0.025 (0.10)
Constant	Yes	Yes	Yes
Number of autoregressive lags	4	4	4
Observations	471	471	471

Newey-West t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Columns regress wage inflation on positive and negative monetary policy shocks and other covariates. Wage inflation is seasonally adjusted annual percent change of average hourly earnings of production and nonsupervisory employees for the total private sector taken from the Federal Reserve Economic Database. The monetary policy shocks are the structural shocks from Coibion and Gorodnichenko (2012). The number of autoregressive lags is chosen by maximizing the BIC. Column (1) has only the contemporaneous monetary policy shock, while column (2) includes the first lag of the positive shock, and column (3) includes lagged values for both the positive and negative shock. We can reject symmetry at either the 10% or 5% significance level for all specifications. The sample is monthly data from March 1969 to December 2008.

unaffected by using 12 autoregressive lags). The results are in table 4. On the whole, the positive shocks are much larger in magnitude and more statistically significant. We can reject symmetry at either the 10% or 5% significance level depending on the specification.

The prediction that these shocks should have asymmetric effects on wage inflation is a purely nominal implication of this model that is not generated by alternative theories of asymmetric business cycles like the ones driven by financial frictions that only bind in recessions.

As a further check on these results, I conduct a placebo test by replacing wage inflation with headline CPI inflation and report the results in table 5. The model predicts that price inflation should exhibit smaller asymmetries than wage inflation in response to monetary shocks. In table 5, the point estimates in the specifications for contemporaneous positive and negative monetary shocks are virtually identical, including specifications with no autoregressive lags or differing numbers of lags for the monetary shock, and the hypothesis that positive and negative shocks have the same

impact cannot be rejected.

4.3 Cross-sectional distribution of wage changes

Next, we look at the cross-sectional distribution of wages in different countries and time periods. Dickens et al. (2007) demonstrate that the cross-sectional distribution of wage changes is both skewed towards the right, and exhibits bunching at zero.

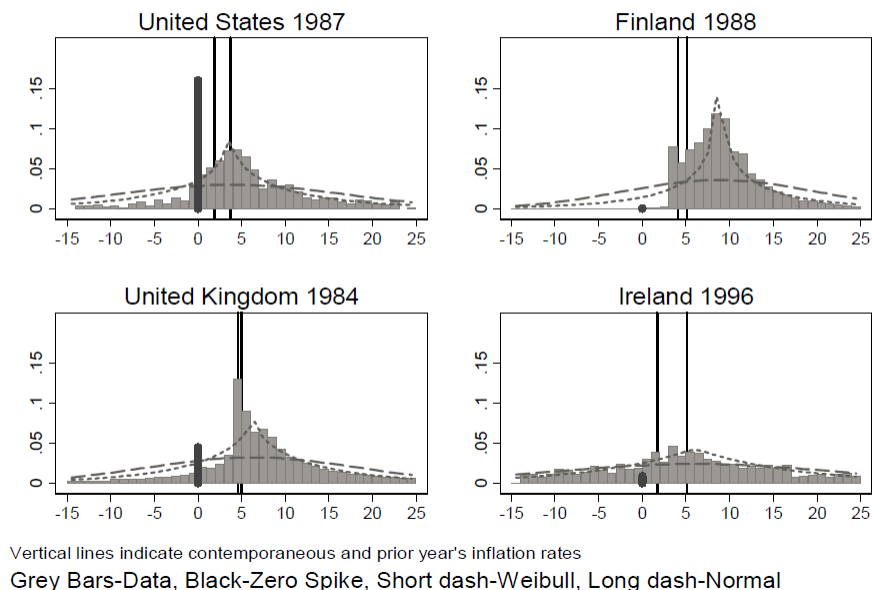


Figure 5: Dickens et al (2007) cross sectional distribution of wages in different countries and time periods.

Dickens et al. (2007) identify two forms of wage rigidity. The first, which they call “nominal rigidity”, is a large point mass at zero wage change, the second, which they call “real rigidity”, is an asymmetric distribution of wage changes around the average inflation rate. An illustration of this can be seen in figure 5, taken from Dickens et al. (2007). We see that the UK in 1984, where both current and last years’ inflation rates were around five percent, had an asymmetry at five percent. On the other hand, in countries where the inflation rates were lower and less stable, the asymmetry was at zero.

The model presented in section 2 has a degenerate cross-sectional distribution, but it can easily be extended to have cross-sectional heterogeneity. Following Lucas (1973), consider a continuum of islands indexed by elements of the $[0, 1]$ interval, with each island inhabited by a worker and an employer. Worker-employer pair i observe a noisy island specific signal $s_i = \varepsilon + \varepsilon_i$ of the log price level $p = \mu + \varepsilon$, and then write a wage contract. Crucially, we assume that the worker considers

Table 5: Responsiveness of Price Inflation to Monetary Policy Shocks

	(1)	(2)	(3)
	π_t	π_t	π_t
ε_t^+	0.073 (0.07)	0.065 (0.07)	0.052 (0.07)
ε_t^-	-0.069 (0.08)	-0.056 (0.09)	-0.077 (0.09)
ε_{t-1}^+		0.059 (0.07)	0.021 (0.07)
ε_{t-1}^-			0.134 (0.10)
Constant	Yes	Yes	Yes
Number of autoregressive lags	4	4	4
Observations	475	475	475

Newey-West t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Notes: Columns regress headline annual CPI inflation on positive and negative monetary policy shocks and other covariates. CPI inflation data is from the Federal Reserve Economic Database. The monetary policy shocks are the structural shocks from Coibion and Gorodnichenko (2012). The number of lags of the inflation rate are chosen to mimic the ones in table 4, though the results are robust to including more lags. Column (1) has only the contemporaneous monetary policy shock, while column (2) includes the first lag of the positive shock, and column (3) includes lagged values for both the positive and negative shock. We cannot reject the hypothesis of symmetry. The sample is monthly data from March 1969 to December 2008.

the signal-to-noise ratio to be ambiguous. As before, when worker utility is log, the prevailing log wage w in island i is

$$w_i = \mu + \frac{\sigma^2}{\sigma^2 + \sigma_s^2(s_i)} s_i + d.$$

where $\sigma_s(s_i) = \bar{\sigma}_s$ whenever $s_i \leq 0$, and $\underline{\sigma}_s$ otherwise. This means that the cross-sectional distribution of wages will be discontinuous around the expected price level μ , with higher variance on the right-hand side and bunching on the left-hand side. If the aggregate shock ε is sufficiently large, the discontinuity and bunching disappear. That is, when the unexpected monetary shock is large (high surprise inflation), no asymmetry is observed in the cross-sectional distribution, see figure 6.

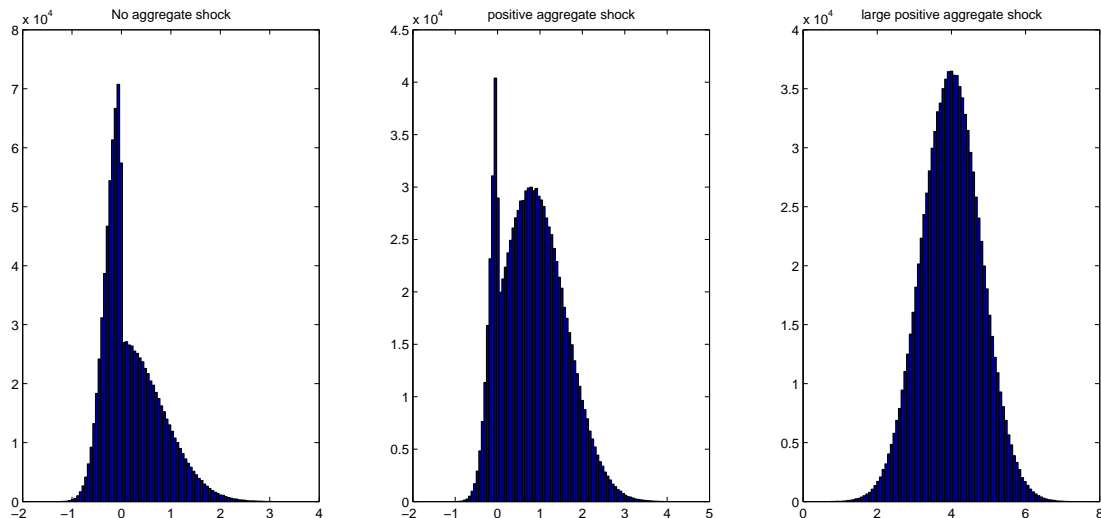


Figure 6: Theoretical cross-sectional wage-change distributions for different aggregate monetary shocks.

Crucially, the model implies that the key point of asymmetry is the ex-ante expected price level (the price level before the signal is observed). This means that, in this model, there is nothing special about zero per se, unless households believe that they are in a very low inflation environment and that absent any signal, prices are not going to change. Conversely, in environments with high and stable inflation, we would observe an asymmetry not at zero, but around expected inflation. Where the asymmetry appears will depend on household expectations in the absence of any new information. It is difficult to infer this from the data available, but the empirical evidence presented in Dickens et al. (2007) is consistent with the idea that the location of asymmetry is higher than zero in environments with persistently high inflation. Furthermore, if the model presented in this paper is augmented with agents who exhibit asymmetric money illusion (as argued by Fehr and Tyran (2001)) then we can capture both the asymmetry around the expected inflation rate and the bunching at wage-freezes using only the price-expectations of households without invoking

loss-aversion or fairness norms.

A further finding by Dickens et al. (2007), as well as Holden and Wulfsberg (2009), is that the degree of real wage rigidity is strongly correlated with union density. Again, the basic model in section 2 can naturally be extended to account for this finding. In particular, note that the degree of rigidity does not solely depend on the degree of ambiguity, but also on the relative elasticities of labor supply and labor demand – or, loosely speaking, the bargaining power of workers and employers. The kinked beliefs of the workers only affect their wage to the extent that workers can withdraw labor in response to their perceived real wage. In particular, the model in section 2 assumed that the workers’ outside option is exogenous and constant. This makes labor supply completely elastic, since workers effectively make an ultimatum to the the employers and refuse to supply any labor when wages are lower than what they demand. Consider, instead the following log labor supply curve

$$l = \gamma(w - \tilde{E}(p|s) - d),$$

where l is log labor and the elasticity of labor supply is given by γ . When γ tends to infinity, we recover the previous set up. On the other hand, when $\gamma = 0$, labor supply is completely inelastic at fixed supply. Let log labor demand be given by

$$l = \frac{1}{1 - \alpha}(\log(\alpha) + E(p|s) - w),$$

easily derived from profit maximization with a Cobb-Douglas production function. The equilibrium log wage is given by

$$w = \kappa(\log(\alpha) + E(p|s)) + (1 - \kappa) \left(\tilde{E}(p|s) + d \right),$$

where $\kappa = \frac{1}{\gamma(1-\alpha)+1} \in [0, 1]$.

The equilibrium nominal wage is a convex combination of the beliefs of the workers and the beliefs of the employers. In the extreme case of infinitely elastic labor supply, $\gamma = \infty$, only the beliefs of the workers matters and we get maximum rigidity. In the other extreme of completely inelastic labor supply, $\gamma = 0$, only the beliefs of the employer matter. In particular, in the completely inelastic labor supply case, ambiguity has no effect on equilibrium wages. This is intuitive: if workers cannot withdraw their labor in response to the wage offer, then wages are determined solely through competition between employers. If employers are not adversely affected by inflation, then the equilibrium wage will not exhibit a discontinuity around the expected inflation rate even if employers are ambiguity-averse.

So, the degree of bargaining power, captured here by the workers’ ability to withdraw labor when wages fall, affects the degree of rigidity in wages. This is consistent with the empirical findings of Dickens et al. (2007) who find that countries where unions have more power exhibit more wage rigidity of the kind generated by this model (i.e. asymmetry around the expected inflation rate).

4.4 Is Ambiguity-Aversion Necessary?

While ambiguity aversion is consistent with the evidence I provided, it is not the only theory that could generate these predictions. In particular, any theory that delivers convex conditional expectations will generate similar predictions. The simplest alternative theory is a Bayesian expected-utility maximizer. Since professional forecasters exhibit no convexity in their beliefs, there must then be something unusual about the priors of the households. In particular, priors that assume the signal is more accurate when there is accelerations of the inflation rate than decelerations will generate very similar results to mine. However, these priors will be incorrect and hard to justify intuitively. Furthermore, the professional forecasters will be objectively doing a better job.

The virtue of ambiguity-aversion, other than its tractability, is that that there is no sense in which households are acting irrationally or making a mistake. If households do not know the precise mapping between aggregate statistics and the prices relevant for them, it is reasonable for them to rely on robustness heuristics – indeed, this was the original motivation for axiomatic theories of ambiguity-aversion.

5 Normative Analysis

One of the advantages of having a microfoundation for downward wage rigidity is that it allows us to deal with normative questions in a more satisfying manner. In this section 5.1, I derive optimal monetary policy, and in section 5.2, I analyse the welfare costs of business cycles.

5.1 Optimal Monetary Policy

Received wisdom in Keynesian economics is that that downward wage rigidity implies that the central bank should have an inflationary bias. Inflation is said to “grease the wheels” of the labor market since it allows wage cuts to take place that would otherwise not have occurred. In this section, I show that this intuition holds in my model if we take the conditional expectation function of the households as exogenous, but fails if we account for the fact that household expectations will react to the change in policy.

Consider a scenario where the central bank has some, but not complete, control over the distribution of demand shocks that hit the economy. Crucially, suppose that although the central bank can affect the distribution of shocks, it has no control over the distribution of the public signal. In other words, the central bank chooses a distribution of demand shocks to minimize expected losses, taking as given the information content (and ambiguity) of a noisy signal.

Most central banks are tasked with maintaining price stability and full employment. In a model like the one sketched above, with only aggregate demand shocks, price stability and deviations from first-best employment are both log-linear functions of the level of the monetary surprise. In

particular, if we denote first-best employment by l^{fb} , then

$$l - l^{fb} = \frac{1}{1 - \alpha}(m - \tilde{E}(m|s)),$$

where first-best employment is employment in the perfect information world. On the other hand, $m - \tilde{E}(m|s)$ also captures price instability. So, I assume that the central bank's loss function is given by

$$L(g) := E_g \left(\left(m - \tilde{E}(m|s) \right)^2 \right),$$

where g is the marginal distribution of demand shocks m , and the expectation is taken with respect to g . I assume that if the central bank takes no action, demand shocks will have a reference distribution q . The central bank chooses g to minimize its losses subject to the requirement that g is not too different from q . I formalize "not too different" using the Kullback-Leibler divergence, an analytically tractable measure of difference between probability distributions.

5.1.1 Naive Policy

In this section, I consider the problem of a central bank who takes the function mapping signals to beliefs of the household as given, and does not internalize the fact that changing the distribution of demand shocks will affect how signals are mapped to conditional expectations. In other words, the central bank solves the following problem

$$\min_{g(m)} \iint (m - \phi(s))^2 f(s|m)g(m)dsdm$$

such that

$$\begin{aligned} \int q(m) \log(g(m))dm - \int q(m) \log(q(m))dm &\leq K \\ \int g(m)dm &= 1, \end{aligned}$$

where q is the distribution of demand shocks when the central bank is passive, $f(s|m)$ is the density of the signal conditional on the monetary policy shock, and $\phi(s)$ is household expectations of the demand shock conditional on the signal, which the bank takes as exogenous. The first constraint requires that the distribution of demand shocks the bank chooses be sufficiently close to the reference distribution q in Kullback-Leibler terms. The second constraint ensures that the chosen density implies a valid probability distribution. The slack non-negativity constraints have been suppressed since they are implied by the first constraint.

The Lagrangian is given by

$$\min_{g(m)} \iint (m - \phi(s))^2 f(s|m)g(m)dsdm - \lambda \int q(m) \log(g(m))dm - \mu \int g(m)dm.$$

The first order condition is given by

$$\begin{aligned} \frac{d}{dt} \iint (m - \phi(s))^2 f(s|m)(g(m) + th(m))dsdm \\ - \lambda \int q(m) \log(g(m) + th(m))dm - \mu \int g(m) + th(m)dm \Big|_{t=0} = 0, \quad \forall h \end{aligned}$$

At the optimum, $g(m)$ solves the following equation

$$\int (m - \phi(s))^2 f(s|m) - \lambda \frac{q(m)}{g(m)} - \mu = 0.$$

Rearrange this to get

$$g(m) = \frac{\lambda q(m)}{\int (m - \tilde{E}(m|s))^2 f(s|m)ds - \mu}, \quad (13)$$

where $\tilde{E}(m|s)$ is substituted for $\phi(s)$.

This first order condition is very intuitive to interpret. Draws of the monetary shock m with large expected squared error in the household's forecast, $E((m - \tilde{E}(m|s))^2|m)$, are less likely to occur relative to the reference distribution q . In other words, if households are more likely to have incorrect beliefs during deflationary episodes than inflationary episodes, then the central bank will reduce the probability of deflationary shocks. This is despite the fact that the central bank's loss function treats under- and over-employment symmetrically.

Since we found household beliefs to be more likely to be incorrect after disinflationary periods than inflationary periods, equation (13) suggests that the central bank should maintain an inflationary bias in policy. This is in keeping with the intuition, and the advice, found in papers like Akerlof et al. (1996) or Kim and Ruge-Murcia (2009), that recommend positive steady state inflation in the presence of downwardly sticky wages. However, in the context of this model, this line of reasoning is susceptible to the Lucas critique if the conditional expectations of households respond endogenously to the distribution of demand shocks.

Before proceeding to the case with endogenous expectations, let us get a better sense for how the solution behaves with the following numerical example. This example shows that, the naive optimal policy will feature an inflationary bias. Suppose that the signal s is given by

$$s = m + \varepsilon,$$

where ε is a mean-zero normally distributed noise term with variance $\sigma \in [\underline{\sigma}, \bar{\sigma}]$. Then

$$\tilde{E}(m|s) = \max_{\sigma \in [\underline{\sigma}, \bar{\sigma}]} \int m \frac{f(s|m, \sigma)g(m)}{f(s|\sigma)} dm, \quad (14)$$

where

$$f(s|m, \sigma) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp\left(-\frac{(s-m)^2}{2\sigma^2}\right), \quad (15)$$

and

$$f(s|\sigma) = \int f(s|m, \sigma)g(m)dm. \quad (16)$$

Equations (13), (14), (15), and (16) determine the equilibrium of this economy.

Let the reference distribution g be a standard normal distribution with mean 0 and variance 1. By calibrating $\underline{\sigma}$, $\bar{\sigma}$, and λ we can compute the equilibrium distribution of monetary shocks. We can calibrate $\underline{\sigma}$ and $\bar{\sigma}$ by fitting a piecewise linear regression to the expectations data. The slope of the piecewise linear function ψ gives the signal-to-total variance ratio, which in turn pins down $\underline{\sigma}$ and $\bar{\sigma}$. A good estimate seems to be $\underline{\sigma} = 0.7$ and $\bar{\sigma} = 2$. Calibrating λ is harder, so we can plot solutions for a range of λ to get a sense of what the optimal solution looks like. In figure 7, we see that as the constraint on the central bank becomes looser, the distribution of shocks becomes more positive and concentrated. For comparison, figure 8 shows that without ambiguity, the distribution simply becomes more concentrated, but there is no inflationary bias. This lines up with the received wisdom that central banks should have an inflationary bias because of downward wage rigidity.

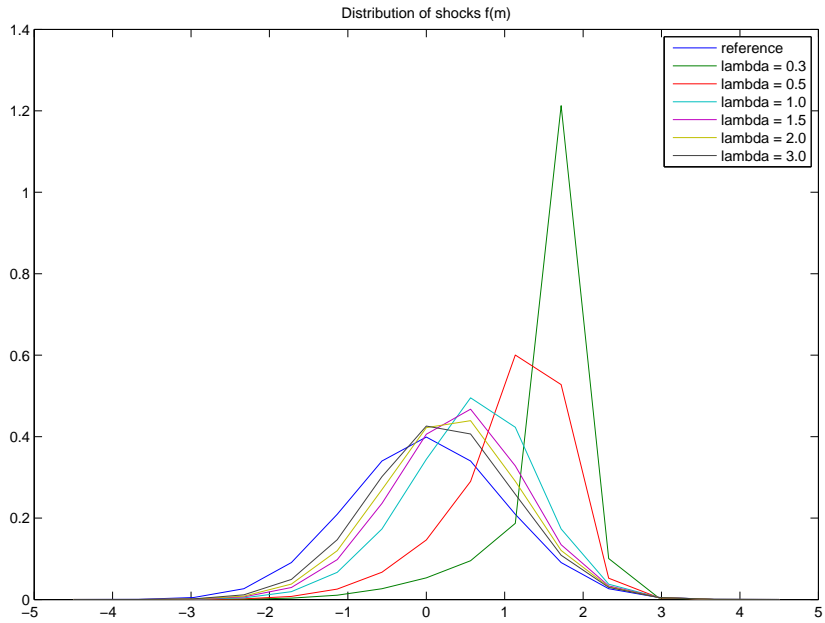


Figure 7: The marginal distribution of monetary shocks

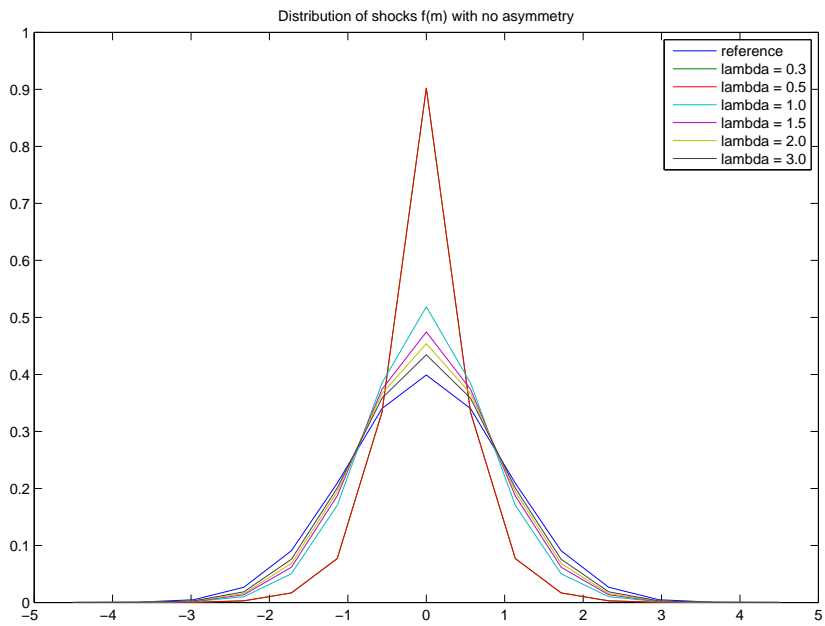


Figure 8: The marginal distribution of monetary shocks with $\underline{\sigma} = \bar{\sigma} = 1$.

5.1.2 Sophisticated Policy

The intuitive result in the previous section is in line with other work in recommending inflationary bias in the presence of downward wage rigidity. However, this result depends crucially on the assumption that the function mapping signals to conditional expectations for the households is fixed. If the central bank takes into account the fact that changing the distribution of monetary shocks changes the signal-extraction problem faced by households, then the inflationary bias disappears.

To that end, consider a central bank that faces the following problem:

$$\min_{g(m)} \iint (m - \phi(s))^2 f(s|m)g(m)dsdm$$

such that

$$\begin{aligned} \int q(m) \log(g(m))dm - \int q(m) \log(q(m))dm &\leq K \\ \int f(m)dm &= 1, \\ \phi(s) &= \max_{\sigma \in [\underline{\sigma}, \bar{\sigma}]} \int \frac{mf(s|m, \sigma)g(m)}{f(s|\sigma)}dm. \end{aligned}$$

The first order condition (omitted) for this problem is harder to interpret. Instead I plot example solutions using a normal error term and a normal reference distribution in figure 9. Unlike the previous section, we see no inflationary bias in the central bank's optimal response, even though the degree of the asymmetry is very extreme. The reason is that if the central bank attempted to skew the distribution towards more inflationary shocks, conditional expectations of households would take this skew into account when interpreting the signal.

The results of this section do not prove that zero percent inflation is the optimal inflation rate. In fact, in this model, the mean value of the inflation rate, as long as it is known by all agents, has no effect on welfare, since wages and prices are flexible. In practice, there are other reasons why we might want to implement a positive inflation target, ranging from concerns about hitting the zero lower bound to other causes of downward wage rigidity besides the one studied here (for instance a nominal fairness norm).

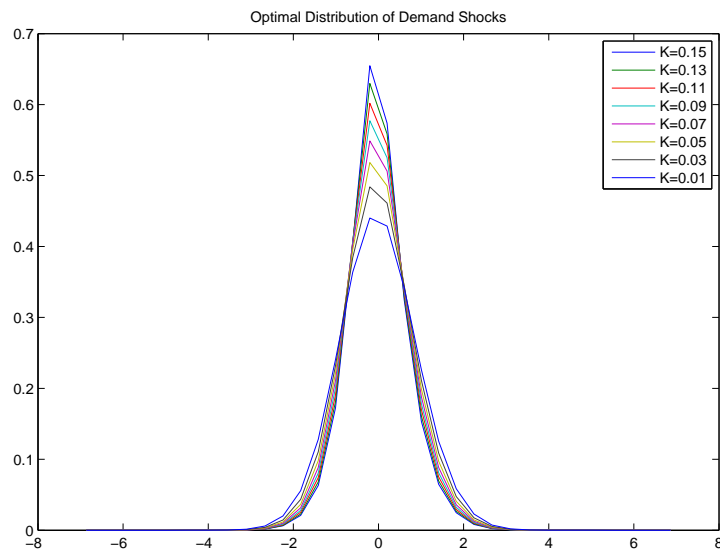


Figure 9: The optimal distribution of monetary shocks, with $\underline{\sigma} = 1$, $\bar{\sigma} = 10$.

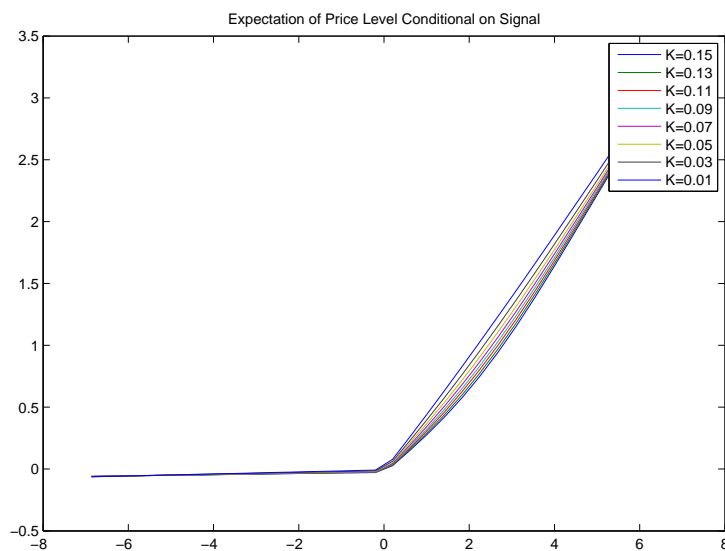


Figure 10: The expectation of the price level conditional on the signal, with $\underline{\sigma} = 1$, $\bar{\sigma} = 10$.

5.2 Costs of Business Cycles

In this environment, demand shocks are more costly to welfare than in standard models of business cycles. Lucas (1987), in a highly influential study, performs a back-of-the-envelope calculation that implies that the welfare costs of ordinary business cycles, measured in units of life-time consumption, are extremely small (around one-twentieth of one percent). The basic intuition underlying this result

is that negative shocks are cancelled out by positive shocks, resulting in second order gains from demand-management policies. However, as pointed out by Schmitt-Grohé and Uribe (2011), in a world with asymmetric rigidities, such calculations need not be true. In the present environment, as seen in figure 4, negative shocks cause far larger drops than positive shocks – therefore, demand-management policy can reap first-order gains.

To formalize this intuition, we can replicate the calculation in Lucas (1987) for the present model. Let

$$c_t^{det} = c_0 e^{gt}$$

represent a deterministic consumption path growing at rate g starting from c_0 . Let the stochastic consumption stream be

$$c_t = c_0 e^{gt} \exp(\bar{\kappa} \mathbf{1}(\varepsilon_t \leq 0) \varepsilon_t + \underline{\kappa} \mathbf{1}(\varepsilon_t > 0) \varepsilon_t),$$

where ε_t is a Gaussian- $(0, \sigma^2)$ demand shock, and $\bar{\kappa} > \underline{\kappa}$ corresponds to the piecewise-linear slopes of (12). This is equilibrium consumption in a model like the one presented above that also features deterministic growth. To measure the welfare costs of demand shocks in permanent consumption units, set

$$\sum_{t=0}^{\infty} \beta^t u(\lambda c_t^{det}) = \mathbb{E} \left(\sum_{t=0}^{\infty} \beta^t u(c_t) \right),$$

and solve for λ . Note that the expectation on the right-hand side features no ambiguity-aversion, but is the objective probability distribution of $\{c_t\}_{t=0}^{\infty}$ given normally distributed demand shocks. Following Lucas (1987), assume CRRA utility with risk aversion parameter γ . Then we can derive the following analytical expression for λ

$$(1 + \lambda)^{1-\gamma} = \frac{1}{2} \left\{ \exp((\gamma - 1)\bar{\kappa}(1 + (\gamma - 1)\bar{\kappa})\sigma^2) \left[1 + \Phi \left(\frac{1 + 2(\gamma - 1)\bar{\kappa}\sigma}{2\sqrt{2}} \right) \right] + \exp((\gamma - 1)\underline{\kappa}(1 + (\gamma - 1)\underline{\kappa})\sigma^2) \left[1 - \Phi \left(\frac{1 + 2(\gamma - 1)\underline{\kappa}\sigma}{2\sqrt{2}} \right) \right] \right\},$$

where Φ is the CDF of a standard normal distribution. Note that if we set $\bar{\kappa} = \underline{\kappa} = 1$, we recover the original calculation done by Lucas. To get a sense for how large this cost is, Lucas calibrates his model by letting $\gamma \in [1, 4]$ and $\sigma = 0.032$. The standard deviation of the shocks are taken from the residuals of a linear regression. The present model implies that such a procedure would underestimate the variance of the true underlying shocks. This harks back to the debate between Romer (1986) and De Long and Summers (1988) about whether macroeconomic policy reduces the variance of shocks or fills in the troughs without shaving the peaks. In the table below, I take $\sigma = 0.032$ and $\bar{\kappa} = 1$, to make my results directly comparable with those of Lucas (1987), with the caveat, that re-estimating σ would result in even larger differences. In particular, the variance of

the consumption process I specify is $(1 + \underline{\kappa}^2)\sigma^2/2$ which is strictly less than the variance used by Lucas as long as $\underline{\kappa} < 1$.

		γ			
		1	2	3	4
	0	25.28	25.62	25.98	26.34
	0.1	22.86	23.24	23.63	24.03
	0.2	20.45	20.87	21.3	21.74
	0.3	18.03	18.5	18.98	19.47
	0.4	15.6	16.13	16.67	17.21
$\underline{\kappa}$	0.5	13.18	13.77	14.36	14.97
	0.6	10.75	11.41	12.07	12.74
	0.7	8.315	9.048	9.787	10.53
	0.8	5.88	6.695	7.514	8.337
	0.9	3.441	4.345	5.251	6.159

Table 6: The ratio of λ in this model to that in Lucas (1987).

The results of the calibration are in table 6. We see that even a modest amount of asymmetry can substantially increase the welfare costs of demand shocks for the US. In particular, if we calibrate κ using table 1, then the welfare cost of demand-driven business cycles are approximately 1% percent of life-time consumption, or about 20 times the cost found by Lucas (1987). There are reasons to believe that these estimates are a lower bound on the welfare costs even in the context of a complete markets, representative consumer economy. First, according to the model, the variance of the underlying shocks in the data is larger than what one would estimate from the residuals of a least squares regression. Second, as we will see in the next section, in a dynamic model, ambiguous information can cause distortions in the deterministic steady-state of a linearized model and make negative shocks more persistent than positive shocks, further increasing the welfare costs of shocks in the model.

6 New Keynesian Model with ambiguous sticky wages

In this section, I embed ambiguous information quality into a standard New Keynesian model with sticky wages. Other than showing that our earlier intuitions survive in this context, I show that in a New Keynesian model time-varying ambiguity is observationally equivalent to a supply or cost-push shock. I also show that ambiguity not only causes the amplitude of positive and negative shocks to be asymmetric, but it can also change their persistence.

In a typical New Keynesian model with sticky wages, households are monopolistically-competitive suppliers of their labor. In such a world, it is no longer the case that inflation is bad news and disinflation is good news, since monopolists care about both the relative price and the quantity of

what they sell. Therefore, I impose kinked beliefs on the households without deriving it from their preferences. This is an artifact of the way sticky wages are modelled in the New Keynesian model – in real life, most households do not set their own wages subject to downward sloping labor demand. One could get around this problem by having firms set wages instead, as in the earlier model, however, it is also interesting to put kinked household beliefs into the work-horse New Keynesian model since, independent from the microfoundations, earlier empirical results imply that household inflation expectations are indeed kinked in the data.

Consider a continuum of households indexed by $i \in [0, 1]$. Household seek to maximize

$$\tilde{E}_t \left(\sum_{t=t_0}^{\infty} \beta^t \frac{C_{it}^{1-\gamma}}{1-\gamma} - \frac{L_{it}^{1+\varphi}}{1+\varphi} \right),$$

where \tilde{E}_t represents expectation with respect to kinked beliefs in period t . There is a representative firm that produces the consumption good Y using technology

$$Y_t = A_t L_t,$$

where A_t is a productivity shock and L_t is a CES aggregate of labor inputs

$$L_t = \left(\int_0^1 L_{it}^{1-\frac{1}{\eta}} di \right)^{\frac{\eta}{\eta-1}}.$$

This implies that labor demand is given by

$$l_{it} - l_t = -\eta(w_{it} - w_t), \tag{17}$$

where lower case variables are in logs, and w_t is the log of the CES wage aggregate. Assume that due to free-entry, the firm makes zero profits in equilibrium, therefore

$$w_t - p_t = a_t. \tag{18}$$

Assume that firms are subject to a cash in advance constraint for the labor they purchase

$$w_t + l_t = \theta_t, \tag{19}$$

where θ_t is a stochastic process representing the money supply. Let

$$\theta_t = \theta_{t-1} + v_t, \quad v_t \sim \mathcal{N}(0, \sigma_v^2).$$

Assume that agents receive a noisy public signal x_t of the stance of monetary at the start of the

period

$$x_t = v_t + \varepsilon_t, \quad \varepsilon_t \sim \mathcal{N}(0, \sigma_\varepsilon^2).$$

As before, households do not know the true signal-to-noise ratio. Suppose agents only know that $\sigma_\varepsilon \in [\sigma_\varepsilon - d, \sigma_\varepsilon + d]$, where $d > 0$ is a parameter that captures the amount of ambiguity or Knightian uncertainty.

The timing of this model will be similar to Angeletos and La'O (2009): at the beginning of the period, an exogenous fraction $1 - \lambda$ of households set their wages optimally subject to their information set and Calvo frictions. At the end of the period, v_t becomes common knowledge, and consumption and production take place. I assume that a monopoly tax eliminates the markup.

The log-linearized optimal reset wage is given by

$$w_{it} = \tilde{\mathbb{E}}_t \left[(1 - \beta\lambda) \sum_{k=0}^{\infty} (\beta\lambda)^k (mrs_{i,t+k|t} + p_{t+k}) \right], \quad (20)$$

where $mrs_{i,t+k|t}$ is log marginal rate of substitution for household i at time $t + k$ conditional on the wage being set in t . Observe that

$$\begin{aligned} mrs_{i,t+k|t} &= \gamma c_{it} + \varphi l_{it}, \\ &= \gamma c_t + \varphi l_{it}, \\ &= \gamma y_t + \varphi (l_t - \eta(w_{it} - w_t)), \\ &= \gamma a_t + (\gamma + \varphi) l_t - \varphi \eta w_{it} + \varphi \eta w_t, \end{aligned} \quad (21)$$

where the second equality follows from complete insurance markets. Use (21), (18), and (19) to get

$$mrs_{i,t+k|t} + p_{t+k} = \underbrace{\frac{\gamma + \varphi}{1 + \varphi \eta}}_{\alpha} \theta_t + \underbrace{\frac{\varphi \eta - \gamma - \varphi + 1}{1 + \varphi \eta}}_{1 - \alpha} w_t + \underbrace{\frac{\gamma - 1}{1 + \varphi \eta}}_{\xi_t} a_t. \quad (22)$$

Note that

$$\tilde{\mathbb{E}}_t \theta_t = \theta_{t-1} + \psi_t x_t,$$

where $\psi_t = \bar{\psi} = \sigma_v^2 / (\sigma_v^2 + \sigma_\varepsilon^2 - d)$ if $x_t \geq 0$, and $\psi_t = \underline{\psi} = \sigma_v^2 / (\sigma_v^2 + \sigma_\varepsilon^2 + d)$ if $x_t < 0$.

Conjecture an equilibrium where

$$w_{it} = b_1 w_{t-1} + b_2 \psi_t x_t + b_3 \theta_{t-1} + b_4 \xi_t + b_5. \quad (23)$$

Observe that, from aggregation,

$$\begin{aligned} w_t &= \lambda w_{t-1} + (1 - \lambda)w_{it}, \\ &= \lambda w_{t-1} + (1 - \lambda)(b_1 w_{t-1} + b_2 \psi_t x_t + b_3 \theta_{t-1} + b_4 \xi_t + b_5). \end{aligned} \quad (24)$$

Note that we can write (20) recursively

$$\begin{aligned} w_{it} &= (1 - \beta\lambda) \tilde{E}_t (mrs_{it|t} + p_t) + \beta\lambda \tilde{E}_t (w_{i,t+1}). \\ &= (1 - \beta\lambda) \tilde{E}_t (\alpha\theta_t + (1 - \alpha)w_t + \xi_t) + \beta\lambda \tilde{E}_t (w_{i,t+1}), \\ &= (1 - \beta\lambda) \tilde{E}_t (\alpha\theta_t + (1 - \alpha)w_t + \xi_t) + \beta\lambda \tilde{E}_t (b_1 w_t + b_2 \psi_{t+1} x_{t+1} + b_3 \theta_t + b_4 \xi_{t+1} + b_5). \end{aligned} \quad (25)$$

Combine (25) and (24) and, by matching coefficients, derive expressions for b_1, b_2, b_3, b_4 , and b_5 . This requires noting that

$$\tilde{E}_t \xi_t = \xi_t, \quad E_t(\psi_{t+1} x_{t+1}) = \frac{\sigma_x}{\sqrt{2\pi}}(\bar{\psi} - \underline{\psi}),$$

where σ_x denotes the time-varying variance of x_{t+1} . Matching coefficients gives

$$\begin{aligned} b_1 &= (1 - \alpha)(1 - \beta\lambda)(\lambda + (1 - \lambda)b_1) + \beta\lambda b_1((1 - \lambda)b_1 + \lambda), \\ b_2 &= (1 - \beta\lambda)\alpha + b_2(1 - \alpha)(1 - \beta\lambda)(1 - \lambda) + b_2\beta\lambda b_1(1 - \lambda) + \beta\lambda b_3, \\ b_3 &= (1 - \beta\lambda)\alpha + b_3(1 - \alpha)(1 - \beta\lambda)(1 - \lambda) + b_3\beta\lambda b_1(1 - \lambda) + \beta\lambda b_3, \\ b_4 &= (1 - \beta\lambda) + b_4(1 - \alpha)(1 - \beta\lambda)(1 - \lambda) + b_4\beta\lambda b_1(1 - \lambda), \\ b_5 &= b_5(1 - \alpha)(1 - \beta\lambda)(1 - \lambda) + b_5\beta\lambda b_1(1 - \lambda) + \beta\lambda b_5 + \beta\lambda \frac{\sigma_x(\bar{\psi} - \underline{\psi})}{\sqrt{2\pi}}. \end{aligned}$$

Therefore, the wage-reset rule conjectured in (23) is an equilibrium. We can spot two differences between the reset wage (23) and a standard New Keynesian model with sticky wages. First is the presence of the asymmetric response of real variables to monetary shocks. Second, is the presence of the constant term b_5 . This term is an ambiguity premium, and has the same interpretation as ambiguity premia in asset pricing contexts. Ambiguity-averse households try to insure themselves against monetary shocks in the future by setting higher wages than they otherwise would. This results in a steady state level of real wages that is higher than, and output that is lower than, in the case with no ambiguity. This ambiguity premium has exactly the same implications as a mark-up and it generates a distortion of the steady state. Some impulse response functions can be seen in figures 11 and 12. As expected, negative shocks cause larger changes than positive shocks. The persistence of either type of shock, however, is identical, since after the first period, the shock becomes common knowledge.

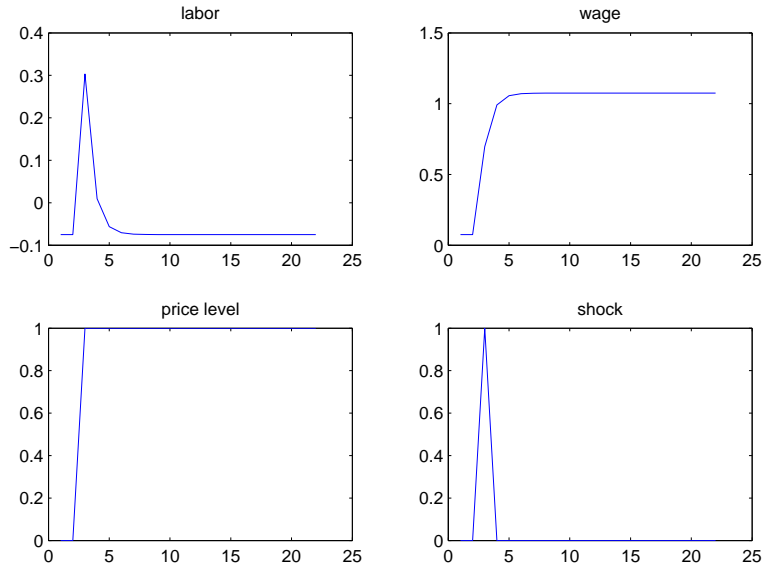


Figure 11: The nominal wage and employment as a function of permanent positive shock to money supply.

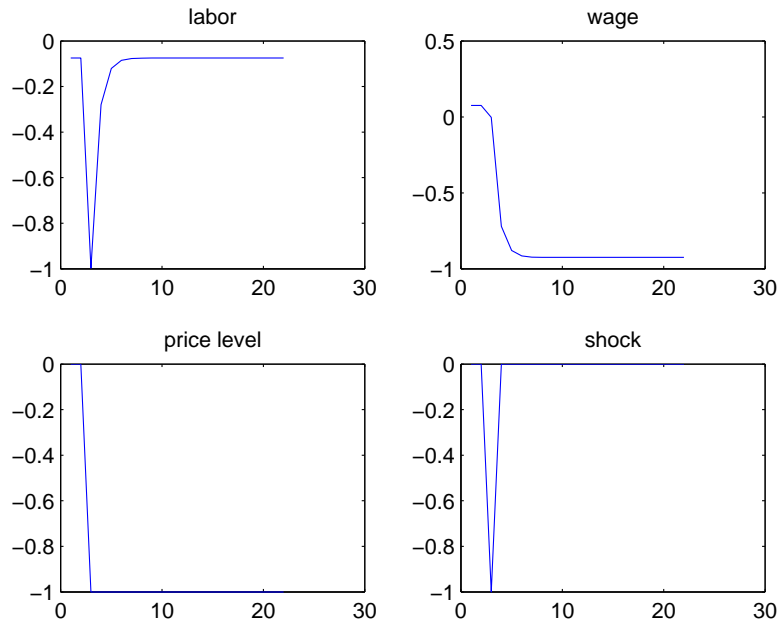


Figure 12: The nominal wage and employment as a function of permanent negative shock to money supply.

6.1 Time-varying ambiguity

Consider a world where the degree of Knightian uncertainty d is a time-varying quantity, suppose for example that d is a random walk. Then in equilibrium,

$$w_{it} = b_1 w_{t-1} + b_2 \psi_t x_t + b_3 \theta_{t-1} + b_4 \xi_t + b_5(d_t), \quad (26)$$

where b_5 is increasing in d_t . This results in cost-push shocks, which increase wages and reduce output, giving a new microfoundation for the existence of a meaningful policy tradeoff between output and inflation for the central bank and violation of the divine coincidence.

6.2 New Keynesian Model with imperfect information and no Calvo frictions

If we eliminate the Calvo friction, the dynamics of the model become degenerate since there is perfect information at the end of each period. An alternative way of endowing the model with some persistence is to follow Woodford (2003). In this set up, ambiguity aversion not only makes the shocks asymmetric on impact, but it also changes their persistence. In particular, disinflationary signals take longer to be incorporated into agents' beliefs with the result that recessions are not just deeper, but also longer-lived, than booms.

Each period, agents receive a public signal x_t as before, but now, instead of the true state being revealed after one period, the true state is never revealed. On the other hand, we dispense with the Calvo friction so that wages can be reset every period. Now

$$\tilde{E}_t(\theta_t) = \sum_{j=0}^{\infty} \left(\prod_{i=0}^{j-1} \psi_{t-i} \right) (1 - \psi_{t-j}) x_{t-j},$$

where ψ_t corresponds to the Kalman gain coefficient under worst case beliefs. We can substitute this into (24) to get

$$w_t = \frac{\alpha}{1 - \alpha} \left[\sum_{j=0}^{\infty} \left(\prod_{i=0}^{j-1} \psi_{t-i} \right) (1 - \psi_{t-j}) x_{t-j} \right] + \frac{1}{1 - \alpha} \xi_t.$$

We see that now, the shock not only affects the magnitude, but also the persistence of the shocks. In particular, negative shocks will on average take longer to be incorporated into the price, which in turn will result in more persistent declines in output. This increases the welfare costs of negative demand shocks.

7 Conclusion

In this paper, I argue that information frictions, coupled with ambiguity-aversion, can result in household expectations of the price level that are more sensitive to inflationary news than disinflationary news. The intuition is that households pay closer attention to and respond more strongly to bad news that their purchasing power might be lower than they thought than good news that their purchasing power is higher than they thought. I confirm that this asymmetry exists in survey data of household inflation expectations, and show that such asymmetric beliefs can give rise to downward rigidity in equilibrium wages. A simple general equilibrium model then implies that nominal and real variables respond asymmetrically to monetary policy shocks. In particular, negative monetary shocks cause larger changes to output than positive monetary shocks. On the other hand, negative monetary policy shocks cause smaller changes to wage inflation than positive monetary shocks. I show that these predictions hold in time series data from the United States.

Normatively, the asymmetry induced by ambiguity aversion increases the welfare costs of business cycles. Since positive and negative shocks do not cancel, reductions in variance reap first-order gains. A back of the envelope calculation shows that these costs are around 20 times higher than the ones in Lucas (1987).

Furthermore, it is typically assumed that downward wage rigidity should imbue the central bank with an inflationary bias, for example in Akerlof et al. (1996) or Kim and Ruge-Murcia (2009). However, this intuition fails to hold in my model if household conditional expectations respond endogenously to inflationary pressure from the central bank. In other words, the idea that in a world with downward wage rigidity, positive inflation “greases the wheels” of the labor market may be subject to the Lucas critique for reasons similar to the long-run Phillips curve.

Finally, I embed this type of ambiguity aversion into a standard New Keynesian model with sticky wages and show that ambiguity about inflation is observationally equivalent to cost push shocks. So one does not need a supply-side, or markups-driven, story to derive a meaningful policy tradeoff between inflation and employment. Furthermore, in a dynamic model, ambiguity aversion means that disinflationary signals take longer to be incorporated into household beliefs and therefore demand-driven recessions are longer-lived than demand-driven booms.

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