Expectations and Fluctuations: The Role of Monetary Policy *

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Abstract

This paper reconsiders the effects of expectations on economic fluctuations. It does so within a competitive monetary economy which features producers and consumers with heterogeneous information about productivity. Agents' expectations are coordinated by a noisy public signal which generates non-fundamental, purely expectational shocks. I show that, depending on how monetary policy is pursued, purely expectational shocks can resemble either demand shocks, as conventionally thought, or supply shocks—increasing output and employment yet lowering inflation. On the policy front, conventional policy recommendations are overturned: inflation stabilization is suboptimal, whereas output-gap stabilization is optimal.

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1 Introduction

Expectations take center stage in macroeconomics and policymaking. Having acknowledged their importance in the most emphatic of ways, the US Federal Reserve recently started publishing its own forecasts of its own interest rate. But, even though recent empirical work (e.g. Beaudry and Portier (2006), Beaudry and Lucke (2010), Barsky and Sims (2011, 2012), Schmitt-Grohe and Uribe (2012), Blanchard et al. (2012)) documents that shocks to expectations indeed contribute significantly to economic fluctuations, the exact way they do so, what drives them, or how they can be handled, remain open questions.

The answers might still be debatable, yet there is something everyone agrees on: when the public overestimates the economy's potential, the economy booms at the cost of inflation. A recent literature (e.g. Blanchard (2009), Angeletos and La'O (2009), Lorenzoni (2011)) discusses this idea, which Lorenzoni (2009) explicitly formalized: non-fundamental purely expectational shocks resemble demand shocks; when positive, they increase output and employment, and they push inflation up. Stabilizing inflation emerges then as a natural policy recommendation (Lorenzoni (2009)).

Nonetheless, a quick look at the US data suggests that consumer sentiment and inflation exhibited an, in fact, negative correlation (-0.53) over the period 1965:Q1 - 2010:Q1 (see Figure 1), whereas, in the second half of the 90s, a period registered as one of exuberant optimism, the US economy combined high cyclical employment with low inflation. In particular, in the period 1995:Q1 - 2001:Q4 , consumer sentiment and cyclical employment exhibited a strong positive correlation ($+0.77$), whereas over the extended period 1990:Q1 - 2002:Q4 (see Figure 2), consumer sentiment exhibited a mildly positive correlation with cyclical employment ($+0.44$), maintaining a mildly negative one with inflation (-0.41). In the same direction, Christiano et al. (2010) document and show within a New Keynesian framework that positive shocks to expectations about future productivity drive the output gap up and inflation down. Evidence casts doubt then on the idea that purely expectational shocks resemble demand shocks.

In this paper, I reconsider the role of expectations in economic fluctuations and develop a theory able to account for the data patterns discussed. I suggest, in particular, that whether purely expectational shocks resemble demand shocks, as conventionally thought, or supply shocks, as the data discussed seems to suggest, depends on the monetary policy pursued. Therefore, any analysis of purely expectational shocks should be performed in light of the monetary policy pursued.

I argue this within an economy which exhibits three key characteristics: it is competitive, cashless, monetary, and features two representative agents, a consumer/worker and a producer, with asymmetric information about the consumer/worker's current productivity. In particular, the consumer/worker's current productivity is known only to the consumer/worker, whereas both agents observe a noisy public signal about the consumer/worker's long-run productivity. The producer's incomplete information is the model's only source of inefficiency.

I let labor decisions be made before the monetary authority steps in and before the commodity market opens, which requires both the consumer and the producer to form expectations about the monetary authority's actions as well as about inflation. Yet, asymmetric information leads agents to form heterogeneous expectations about the monetary authority's actions, which is exactly what opens the door to monetary policy, a feature my paper shares with, among others, Weiss (1980), King (1982) and Lorenzoni (2010). Further, to the extent that inflation partly reflects consumer long-run expectations, which operate through the Euler equation, the producer needs to second-guess the consumer. Consumer expectations thus have real effects too and they do so in this indirect way.

Agents' expectations, however, have different implications for the economy. To see this, consider a positive shock to the noise component of the public signal, which increases both agents' expectations. Consumer expectations about long-run productivity push toward a demand-shock interpretation of purely expectational shocks. A consumption-smoothing motive—expressed through the Euler equation—underlies their effects: a consumer overly optimistic about the long-run prospects of the economy raises his current demand, which pushes prices up. Under incomplete information, the producer overestimates the inflationary pressure to be caused due to the consumer's expectations. As a result, the nominal wage increases more than proportionally relative to prices and a higher real wage prevails, which induces the worker to increase his labor supply and production to expand. On the other hand, producer expectations about current productivity cause shifts in labor demand and push toward a supply-shock interpretation of purely expectational shocks. In particular, a higher real wage reflects the producer's overly optimistic expectations. As a result, employment increases, production expands and, at a certain demand level, prices need to fall for the commodity market to clear.

Whether purely expectational shocks actually resemble demand or supply shocks depends on the monetary policy pursued, and this is precisely the message that my paper bears. To illustrate the role of monetary policy, let a monetary authority set the nominal interest rate based on a standard Taylor rule, targeting current inflation and the current output gap, and fix the nominal interest rate at a certain level. The weight on the output gap proves, in particular, crucial as to how purely expectational shocks manifest themselves. A positive purely expectational shock raises both agents expectations leading to a positive output gap. The more the monetary authority responds to the output gap, the more the producer overestimates the inflationary pressure to be caused once the commodity market opens. Thus, supply expands by even more and the output gap becomes even greater. Then, for the interest rate to remain constant, the inflationary pressure becomes lower, and it can, in fact, turn to a deflationary one for a sufficiently strong response to the output gap. In that case, purely expectational shocks manifest themselves as supply shocks.

The closest paper to mine is Lorenzoni (2009). Lorenzoni (2009) asks whether purely expectational shocks can behave like demand shocks and answers that, indeed, they can do. To show this, he restricts attention to the consumer side within a New Keynesian environment. My paper, instead, considers both the producer and the consumer side within a competitive flexible-price environment. Rather more broadly, it asks how purely expectational shocks behave, and argues that the answer depends on how monetary policy is pursued. To the best of my knowledge, my paper is the first to suggest so. Hence, purely expectational shocks can indeed resemble demand shocks, as Lorenzoni (2009) suggests, when the monetary policy weight on the output gap is low enough, but they can instead resemble supply shocks, when the weight on the output gap is high enough. In the latter case, they push employment and inflation in opposite directions, which is incompatible with the Phillips curve.

Nimark (2013) estimates a model similar to Lorenzoni (2009)—although with a different type of signal and a richer shock structure—and obtains impulse responses to purely expectational shocks which lend full support to the ones proposed here. Further, a supply-shock behavior can reconcile purely expectational shocks with the empirical finding of Barsky and Sims (2012), namely that shocks to expectations about future productivity (which can, in principle, be fundamental or non-fundamental) raise output and substantially lower inflation. Purely expectational shocks within the estimated New Keynesian DSGE model of Barsky and Sims (2012) fail to cause a drop in inflation, which is partly why the authors essentially dismiss them as unable to account for the estimated dynamics of aggregate variables. Blanchard et al. (2012), on the contrary, favor a demand-shock interpretation of purely expectational shocks, based on an estimated model similar to that of Smets and Wouters (2003) and Christiano et al. (2005). Perhaps crucially though, the authors' prior for the weight on the output gap is quite low (0.02), whereas the authors themselves admit that "to identify the role of news and noise in fluctuations one must rely more heavily on the model's structure" (Blanchard et al., 2012, p. 26).

Turning to policy considerations, since the producer's incomplete information is the only source of inefficiency, a monetary authority should, therefore, restore the complete-information equilibrium allocation. To do so it needs to manipulate inflation in such a way that the producer correctly anticipates his revenue. By stabilizing prices it fails to do so because it eliminates the producer's uncertainty only about the prices he will sell at, while it does nothing to ameliorate the producer's uncertainty about the quantity to be sold. Output-gap stabilization, on the contrary, restores optimality: anticipating the monetary authority to respond aggressively to potential deviations of output from its efficient level is what renders producer expectations irrelevant.

That a monetary authority can affect agents' responses to information with its prospective response to variables about which agents are currently asymmetrically informed is a central feature also in Lorenzoni (2010). This feature distinguishes my paper from Weiss (1980) and King (1982), in which monetary policy affects the informational content of prices. Angeletos and La'O (2012) is a recent contribution studying optimal monetary policy under incomplete information. Even though it does so within a quite different environment, it shares a key policy implication with my paper: inflation stabilization is suboptimal. This is because, in both papers, incomplete information acts as a real distortion, eventually breaking the so-called "divine coincidence," an insight also offered by Blanchard and Gali (2007).

Broader relation to the literature. That shifts in expectations play a major role in business cycle fluctuations is an idea with origins at least in Pigou (1926). This idea has recently been revived by the "news shocks" literature, which includes articles by Beaudry and Portier (2004, 2006, 2007), Jaimovich and Rebelo (2009), Christiano et al. (2010), and Barsky and Sims (2011). However, the "news shocks" literature distinguishes between shocks to current and anticipated shocks to future productivity, whereas, crucially, my paper distinguishes between fundamental and non-fundamental shocks to expectations.

As such, my paper lies naturally in the literature following Phelps (1970) and Lucas (1972), which formalized the idea that incomplete information can open the door to non-neutralities of non-fundamental shocks. Like the recent literature, my paper lets information give rise to aggregate shocks and it entirely abstracts from monetary policy shocks:[1] the very existence of incomplete information is independent of the monetary authority's actions. Nonetheless, as I have already noted, it is asymmetric as opposed to incomplete yet symmetric information about the monetary authority's future actions that breaks the policy irrelevance proposed in Sargent and Wallace (1975, 1976), allowing monetary policy to assume center stage. In a sense, monetary policy acts here as a lever and, depending on how it is pursued, it scales up or down the effects of aggregate shocks.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 defines equilibrium and pins down the optimality conditions. Section 4, first, characterizes the benchmark complete-information equilibrium and, subsequently, the incomplete-information one. Second, it demonstrates the paper's central result through two numerical examples,

[1]The early literature focused on monetary shocks. Related papers in the early literature include Polemarchakis and Weiss (1977), Weiss (1980), King (1982), Bulow and Polemarchakis (1983) and, especially, Grossman and Weiss (1982). The recent literature has shifted its focus to aggregate information shocks and is developing in different yet complementary directions. For instance, following Phelps (1983), the works by Woodford (2001), Morris and Shin (2002), Hellwig (2002), Angeletos and Pavan (2007, 2009), Nimark (2008, 2011), Angeletos et al. (2013) and Angeletos and La'O (2009, 2013) emphasize (or formalize within a business-cycle context in the case of Angeletos and La'O (2013)) the role of higher-order beliefs. Mankiw and Reis (2002), Sims (2003), Adam (2007), Mackowiak and Wiederholt (2009) and Paciello and Wiederholt (2012) among other articles emphasize the role of information-processing constraints, which Coibion and Gorodnichenko (2012) explore empirically. Excellent surveys of both the early and the more recent literature are offered in Hellwig (2008), Mankiw and Reis (2010), Lorenzoni (2011) and Veldkamp (2011).

with the discussion deferred to Section 5 . Section 6 evaluates different specifications of the monetary policy parameters and characterizes the optimal ones. Section 7 concludes.

2 Environment

The economy exhibits three key characteristics: it is perfectly competitive, cashless, monetary, and features two representative agents, a consumer/worker and a producer, with asymmetric information about the consumer/worker's productivity. The consumer/worker supplies labor to a representative firm he owns. The firm is managed by the producer and produces a single non-storable commodity. The only relevant financial market is a short-term nominal bond market with the nominal bond price set by a monetary authority according to an interest-rate rule. Time is discrete with an infinite horizon and commences in period 0 . Each period is divided into two stages: in stage 1 , only the labor market opens (and closes), whereas the commodity market and the nominal bond market operate in stage 2 .

The consumer's preferences are given by

$$E^c_{-1} \sum_{t=0}^{\infty} \beta^t \, U(C_t, N_t) \,, \tag{1}$$

where $\beta \in (0,1)$ parametrizes the consumer's time preference, C_t denotes consumption in period t , and N_t denotes employment in period t . Period utility, U , is given by

$$U(C_t, N_t) \;=\; \log C_t \;-\; \frac{1}{1+\zeta}\, N_t^{1+\zeta} \,, \tag{2}$$

where $\zeta > 0$ is the inverse constant marginal utility of wealth ("Frisch") elasticity of labor supply.

The consumer faces a sequence of budget constraints given by

$$P_t\, C_t \;+\; Q_t\, B_{t+1} \;=\; B_t \;+\; W_t\, N_t \;+\; \Pi_t \,. \tag{3}$$

P_t denotes the commodity price in period t , B_{t+1} denotes holdings of nominal bonds purchased in period t and maturing in period $t+1$, Q_t denotes the nominal bond price, W_t denotes the nominal wage, and Π_t denotes the firm's profits that accrue to the consumer.

The firm's technology is

$$Y_t \;=\; A_t\, N_t \,, \tag{4}$$

where Y_t denotes the firm's output and A_t denotes the worker's productivity. The firm's profits are given by

$$\Pi_t = P_t Y_t - W_t N_t . \tag{5}$$

In line with Taylor (1993, 1999), a monetary authority sets the nominal bond price according to the following interest-rate rule:

$$Q_t = \beta \, \Pi_t^{-\phi_\pi} \left(\frac{Y_t}{Y_t^*} \right)^{-\phi_y} . \tag{6}$$

Π_t denotes inflation in period t, which is defined as $\Pi_t \equiv \frac{P_t}{P_{t-1}}$; Y_t^* denotes the natural level of output, which is defined as output produced in the absence of any frictions. I will henceforth call output gap the distance of output from its natural level, Y_t / Y_t^*. The monetary policy parameters ϕ_π and ϕ_y can take only non-negative values.

2.1 Shocks

The producer faces uncertainty about the worker's productivity, A_t. Let $a_t \equiv \log A_t$ and note that, henceforth, lowercase variables will denote natural logarithms of the respective uppercase variables. Following Lorenzoni (2009), productivity consists of a permanent component, x_t, and a temporary component, u_t, which relate to each other in the following way:

$$a_t \equiv \log A_t = x_t + u_t . \tag{7}$$

The worker knows his productivity, a_t, however its decomposition is unknown to him.

The permanent productivity component, x_t, follows a random walk process

$$x_t = x_{t-1} + \epsilon_t , \tag{8}$$

where ϵ_t is an i.i.d. shock and $\epsilon \sim N(0, \sigma_\epsilon^2)$. The temporary productivity component, u_t, is i.i.d. and $u \sim N(0, \sigma_u^2)$.

All agents observe a noisy public signal about the permanent productivity component

$$s_t = x_t + e_t , \tag{9}$$

where e_t is i.i.d. and $e \sim N(0, \sigma_e^2)$. Shock e is, and I will hereafter call it so, a purely expectational shock. All three shocks u_t, ϵ_t, and e_t are mutually independent.

2.2 Timing, formation of expectations, and information

Activity in each period is spread over two stages: labor decisions are made in stage 1, whereas consumption/saving decisions are made in stage 2. All payments materialize in stage 2 and are perfectly enforceable.

Stage 1 is in turn divided into two sub-stages. In sub-stage 1, the consumer/worker realizes his productivity, a_t, both agents and the monetary authority observe the noisy public signal, s_t, about the permanent productivity component, x_t, and the nominal wage prevails. In sub-stage 2, the worker decides on his labor supply and production takes place. This intra-stage distinction is made possible by the firm's linear technology (4): constant returns to scale imply that the nominal wage in sub-stage 1 of stage 1 is unconditional on the amount of labor to be submitted in sub-stage 2.[2]

In stage 2, the monetary authority steps in to set the nominal interest rate according to the interest-rate rule given by (6) and the commodity market opens. The consumer decides on his bond holdings and consumption at the prevailing prices. With nominal bonds in zero net supply, the nominal bond price adjusts to clear the nominal bond market; with production pre-determined from stage 1, the commodity price adjusts to clear the commodity market.

I will show below that output or employment, given market clearing, or the commodity price, perfectly reveal productivity a_t, which implies that in stage 2 of each period both agents and the monetary authority have identical information. Permanent productivity, x_t, however, will remain unknown to everyone.

Agents need, then, to form expectations about permanent productivity. In doing so, I assume that they use the Kalman filter algorithm, which requires the use of past realizations of the observables, i.e. productivity, a, and the public signal, s, and therefore implies that the state of the economy coincides with the history of observables. In particular, expectations

[2] I have introduced a lag in the labor supply decision in order to prevent it from fully revealing the worker's productivity. Were technology instead to exhibit decreasing returns to scale, such a possibility would not be available. An alternative in that case could be to let labor supply be subject to additional, idiosyncratic to the worker, shocks (e.g. a preference shock). Labor supply would then (generically) be partially revealing about the worker's productivity. In the limit case in which the shock's variance tended to infinity, the producer would dismiss the informational content of labor supply and his information set would coincide with the one here.

evolve as follows:

$$E^p_{t,1}\left[a_t\right] \;=\; E^p_{t,1}\left[x_t\right] \;=\; (1-\mu)\, E^p_{t-1,2}\left[x_{t-1}\right] \,+\, \mu\, s_t \tag{10}$$

$$E^p_{t,2}\left[x_t\right] \;=\; E^c_t\left[x_t\right] = \;(1-k)\, E^c_{t-1}\left[x_{t-1}\right] \,+\, k\left[\theta\, s_t \,+\, (1-\theta)\, a_t\right], \tag{11}$$

where μ, k, θ are coefficients, derived in Appendix A.1, which depend on the shocks' variances σ^2_u, σ^2_ϵ, σ^2_e and lie in $(0,1)$. Expectations are measurable with respect to the agents' information sets and, throughout, I use the shortcut $E^j_t\left[\cdot\right]$ to refer to $E_t\left[\cdot \mid I^j_t\right]$, where $j = \{p, c\}$. Superscript p refers to the producer and superscript c refers to the consumer. Subscripts specify the period; in the producer's case they additionally specify the stage, since the producer's information set differs across stages.

The first equality in (10) follows from (7) and the information specification. If, for instance, s_t was a noisy signal about a_t instead of x_t, the first equality in (10) would break down. Let Ψ_t denote the state of the economy, which is given by $\Psi_t = \{(a_\tau)^t_{\tau=0}, (s_\tau)^t_{\tau=0}\}$. The second equality in (10) uses the fact that the producer's information set in stage 1, $I^p_{t,1}$, is given by $I^p_{t,1} = \Psi_t \backslash \{a_t\}$, whereas the equalities in (11) use the fact that, in stage 2, agents' (and the monetary authority's) information sets coincide with the state, i.e. $I^p_{t,2} = I^c_t = \Psi_t$.

3 Equilibrium

I define equilibrium as follows:

Definition 1 (Equilibrium)**.** *A rational expectations equilibrium under an interest-rate rule* $Q_t\left(\Psi_t\right)$ *consists of prices* $\{P_t\left(\Psi_t\right), W_t\left(\Psi_t \backslash \{a_t\}\right), Q_t\left(\Psi_t\right)\}^\infty_{t=0}$*, an allocation for the producer* $\{N^d_t\left(\Psi_t \backslash \{a_t\}\right), Y_t\left(\Psi_t\right)\}^\infty_{t=0}$*, and an allocation for the consumer* $\{C_t\left(\Psi_t\right), N^s_t\left(\Psi_t\right), B_{t+1}\left(\Psi_t\right)\}^\infty_{t=0}$ *such that:*

1. *Allocations solve the agents' problems, which are laid out below, at the stated prices.*

2. *Markets clear:* $Y_t = C_t$, $N^d_t = N^s_t$, $B_{t+1} = 0$ *for all* t *with* $B_0 = 0$.

I will start with the consumer's problem. The consumer has complete information about the state and, therefore, effectively makes all decisions in stage 1. Given $B_0 = 0$, the consumer chooses consumption, labor supply, and nominal bond holdings to maximize his expected utility (1)-(2), subject to his sequence of budget constraints (3), and a no-Ponzi-scheme constraint, which requires that $B_{t+1} > -\Gamma$, for any $\Gamma > 0$, at all t. The consumer's optimality conditions are

$$N_t^{\zeta} = \frac{W_t}{P_t\, C_t} \tag{12}$$

$$Q_t = \beta\, E_t^c \left[\frac{P_t}{P_{t+1}}\, \frac{C_t}{C_{t+1}}\right], \tag{13}$$

with Q_t set by the monetary authority according to (6).

Equation (12) is the familiar intratemporal labor supply condition, which equates the real wage with the marginal rate of substitution between consumption and leisure. Equation (13) is the intertemporal Euler equation. Given the no-Ponzi-scheme constraint and the fact that nominal bonds are in zero net supply, it requires, in equilibrium, prices and quantities to be such that the demand (supply) for (of) nominal bond holdings is equal to zero at all dates, that is $B_{t+1} = 0$ for all t. Suppressing bond holdings from the state of the economy is therefore harmless.

The producer chooses labor demand in sub-stage 1 of stage 1 to maximize the firm's expected evaluated profits, $E_{t,1}^p\left[\lambda_t\, \Pi_t\right]$, where profits, Π_t, are given by (5) and are evaluated using the consumer/owner's Lagrange multiplier, $\lambda_t = (P_t\, C_t)^{-1}$.[3] Since, I will, henceforth, always refer to the producer's expectations as of stage 1, I will switch to the simpler notation $E_t^p\left[\cdot\right]$. Given the linear technology (4), the solution to the producer's problem requires the producer to accommodate any labor supplied at a nominal wage such that the firm's expected evaluated profits are equal to zero. The nominal wage for which this is the case is given by

$$W_t = \frac{E_t^p\left[\lambda_t\, P_t\, A_t\right]}{E_t^p\left[\lambda_t\right]}, \tag{14}$$

where the term $E_t^p\left[\lambda_t\, P_t\, A_t\right]$ in the numerator denotes expected evaluated marginal revenue, whereas $E_t^p\left[\lambda_t\, W_t\right]$ denotes expected evaluated marginal cost per unit of labor supplied.

[3] One may correctly point out that the consumer/worker's Lagrange multiplier perfectly reveals productivity a_t. Implicitly I have assumed that, at the beginning of each period, the consumer and the producer physically separate, which allows me to abstract from the "Lucas-Phelps" islands framework and consider only one "island" in its stead. That said, by maximizing the firm's evaluated profits, the producer operates the firm in the way the consumer/owner would want him to (see also Chapter 6 in Magill and Quinzii (1996)).

Realized profits, however, are not typically equal to zero, which is absolutely central to this paper. This is because the real wage is typically higher or lower than productivity, yielding losses or profits, respectively, to the firm with losses (profits) subtracted (added) in a lump-sum fashion from (to) the consumer/owner's period wealth.

I will consider only linear rational expectations equilibria. Doing this simplifies considerably the agents' information extraction problems and enables me to use the Kalman filter algorithm to study the evolution of agents' expectations.

A first step is to express in log-linear form the solutions to the agents' problems, (12) - (14):

$$\zeta n_t \;=\; w_t \;-\; p_t \;-\; c_t \tag{15}$$

$$c_t \;=\; -\log\beta \;+\; \log Q_t \;+\; E_t^c\left[c_{t+1} \;+\; \pi_{t+1}\right] \;+\; const \tag{16}$$

$$w_t \;=\; E_t^p\left[a_t\right] \;+\; E_t^p\left[p_t\right] \;+\; const'\,. \tag{17}$$

Likewise, for the interest-rate rule (6):

$$i_t \;\equiv\; \log\frac{1}{Q_t} \;=\; -\;\log\beta \;+\; \phi_\pi\,\pi_t \;+\; \phi_y\left(y_t \;-\; y_t^*\right). \tag{18}$$

Substituting (17) in (15) and adding and subtracting p_{t-1}, and substituting (18) in (16) yields the following two optimality conditions:

$$\zeta n_t \;=\; E_t^p\left[a_t\right] \;+\; E_t^p\left[\pi_t\right] \;-\; \pi_t \;-\; c_t \;+\; const' \tag{19}$$

$$E_t^c\left[c_{t+1}\right] \;-\; c_t \;=\; \phi_\pi\,\pi_t \;+\; \phi_y\left(y_t \;-\; y_t^*\right) \;-\; E_t^c\left[\pi_{t+1}\right] \;+\; const\,. \tag{20}$$

Intratemporal condition (19) is the equilibrium labor market condition, whereas condition (20) is the Euler equation, which I discussed above.

I will now proceed to the characterization of the equilibria.

4 Characterization of equilibria

I will first characterize and discuss the benchmark equilibrium in which the producer has complete information (Section 4.1). Subsequently, I will turn to the incomplete information one (Section 4.2).

4.1 Complete information benchmark

Suppose that the state of the economy is commonly known, i.e. suppose that $I_t^p = I_t^c = I_t^m = \Psi_t$. In this case, the public signal has no effect on output and employment and the real side of the economy is determined independently of the monetary policy pursued. Effectively, the division of a period into two stages ceases to matter.

In particular, under complete information, the real wage is equal to productivity, that is, in logs, $w_t^* - p_t^* = a_t$, where z_t^* denotes the complete-information equilibrium value of variable z_t. It follows then from (15) and market clearing together that

$$n_t^* = 0 \text{ and } y_t^* = a_t . \tag{21}$$

To pin down the nominal side, conjecture that $\pi_t = \vartheta_0 + \vartheta_1 E_t^c[x_t] + \vartheta_2 a_t$. Using the Euler equation (20), confirm then that

$$\pi_t^* = \vartheta_0 + \frac{1}{\phi_\pi} (E_t^c[x_t] - a_t), \tag{22}$$

with the derivations for coefficients ϑ_0, ϑ_1, ϑ_2 collected in Appendix A.2.1.

We can confirm from (21) and (22) that the consumer's expectations about permanent (long-run) productivity, $E_t^c[x_t]$, do have an effect on inflation; however they have no effect on output and employment. To see why, note first that, due to a consumption-smoothing motive expressed by the Euler equation (20), the consumer's current demand depends positively on the consumer's expectations about permanent productivity, whereas it depends negatively on the expected real interest rate, which I denote as r_t. With prices being flexible, the expected real interest rate responds one-for-one to shifts in the consumer's expectations, i.e. $\Delta r_t / \Delta E_t^c[x_t] = 1$, preventing, thereby, the consumer's expectations from having a direct effect on output and employment. To see this point, note that, ignoring constants, by eq. (22), expected inflation is equal to zero, i.e. $E_t^c[\pi_{t+1}] = 0$, which implies that the expected real interest rate coincides with the nominal one, given by (18). That said, use (21) and (22) to confirm that the nominal interest rate responds one-for-one to changes in the consumer's expectations. Of course, changes in current demand lead to according changes in current prices. In particular, the greater the consumer's expectations about permanent productivity are, the greater current demand is, and the greater the inflationary pressure becomes. However, under complete information for the producer, the nominal wage adjusts proportionally to the perfectly-foreseen stage-2 prices, leaving, thereby, the real wage intact and preventing the consumer's expectations from having an indirect effect on output and employment through the producer's expectations about prices.

Turning to monetary policy, it has no real effects due to both agents being able to perfectly foresee the nominal interest rate to prevail in stage 2. However, as I show below, what we really need for monetary policy to be neutral is that agents have symmetric, although possibly incomplete, information about the nominal interest rate to prevail.

4.2 Incomplete information

Suppose now that the producer does not know the consumer/worker's productivity, that is $I^p_{t,1} = \Psi_t \setminus \{a_t\}$, whereas, the consumer, as in the benchmark equilibrium case, has complete information about the state, that is $I^c_t = \Psi_t$. I show below that the monetary authority also has complete information at the time it steps in, that is $I^m_{t,2} = \Psi_t$.

I will assume that an equilibrium exists and will, subsequently, pin it down by guessing and verifying. To this end, let me post the following conjectures about consumption and inflation:

$$c_t = \xi_0 + \xi_1 E^p_t[a_t] + \xi_2 a_t \tag{C1}$$

$$\pi_t = \kappa_0 + \kappa_1 E^p_t[a_t] + \kappa_2 E^c_t[x_t] + \kappa_3 a_t \,. \tag{C2}$$

Conjectures (C1) and (C2) imply that the producer and the monetary authority can fully extract productivity, a_t, by observing production or employment, given market clearing, or inflation, given (11), which indeed establishes that, in stage 2, agents and the monetary authority have complete information, i.e. $I^p_{t,2} = I^c_t = I^m_{t,2} = \Psi_t$.[4]

[4]Conjecturing instead that consumption and inflation depend on the entire history of public signals and productivities would make no difference. This is a direct consequence of the way agents form expectations (see the discussion in Section 2.2), which disciplines the treatment of public signals and productivities within

Conjectures (C1) and (C2), optimality conditions (19) and (20), and market clearing together imply that

$$y_t = \xi_0 + \xi_1 E_t^p[a_t] + (1-\xi_1) a_t \tag{23}$$

$$\pi_t = \kappa_0 + \frac{1}{\phi_\pi}[-(1+\phi_y)\xi_1 E_t^p[a_t] + E_t^c[x_t] + [(1+\phi_y)\xi_1 - 1] a_t] \tag{24}$$

$$\xi_1 = \frac{\phi_\pi - 1 + k(1-\theta)}{\phi_\pi(1+\zeta) - (1+\phi_y)}, \tag{25}$$

where k and θ are the endogenous learning coefficients derived in Appendix A.1, whereas the values of the constant terms, ξ_0 and κ_0, as well as the derivations leading to eq. (23) - (25) are collected in Appendix A.2.

Equation (23) shows that output is a weighted average of productivity and the producer's expectations about it.[5] The respective weights are parametrized by ξ_1, given by (25), and depend on the Frisch elasticity of labor supply, parametrized by ζ, the learning coefficients k, θ, and, importantly, the monetary policy parameters ϕ_π, ϕ_y. I discuss the exact role of all parameters and coefficients below.

The presence of the monetary policy parameters, ϕ_π and ϕ_y, in (23) given (25) leads to the following remark: monetary policy is non-neutral. To see why, express the labor market optimality condition (19) in the following, more general, way:

$$\zeta n_t = E_t^p[a_t] + E_t^p[\pi_t] - E_t^c[\pi_t] - E_t^c[c_t] + const'. \tag{26}$$

To the extent that the monetary authority affects inflation with its actions, namely through the setting of the nominal interest rate, monetary policy has real effects as long as agents form heterogeneous expectations about the monetary authority's prospective actions. Implicit in this argument is that the monetary authority has more information at the time it steps in than the least informed of the agents (here, the producer) has at the time the labor decision

the state. Further, modifying conjecture (C1) by allowing consumption to depend directly on the consumer's expectations would leave the results intact as the consumer's expectations affect output only in an indirect way, which I discuss below.

[5] That the respective weights sum to one is a consequence of preferences being logarithmic in consumption.

is made. Effectively, the time advantage of the monetary authority is then an informational advantage. Crucially, incomplete yet symmetric information about the prospective actions of the monetary authority would render monetary policy neutral, which is an insight this paper shares with, among others, Weiss (1980), King (1982), and Lorenzoni (2010).

To analyze equation (24), it helps to rearrange its terms in the following way:

$$\pi_t = \kappa_0 + \frac{1}{\phi_\pi}\left[\left(E_t^c\left[x_t\right] - a_t\right) - \left(1+\phi_y\right)\xi_1\left(E_t^p\left[a_t\right] - a_t\right)\right]. \tag{27}$$

Equation (27) shows that inflation depends positively on the wedge between the consumer's expectations about permanent productivity, $E_t^c\left[x_t\right]$, and current productivity a_t, whereas, as long as coefficient ξ_1, given by eq. (25), is positive, it depends negatively on the the wedge between the producer's expectations about current productivity, $E_t^p\left[a_t\right]$, and actual current productivity a_t.

With different choices of the monetary policy parameters, ϕ_π and ϕ_y, leading to different combinations of signs of the coefficients in eq. (23) and (24) (equivalently, (23) and (27)), the role of monetary policy emerges as a pivotal one. This suggests that the way shocks affect the economy depends on the monetary policy pursued, a point central to my paper. To illustrate it, I will proceed by comparing the effects of two commonly considered pairs of monetary policy parameters.

4.2.1 Numerical examples

In both cases I consider, I let the monetary policy weight on inflation, ϕ_π, be equal to 1.5. What distinguishes the two cases then, is the weight on the output gap, ϕ_y. In the first case, to which Figures 3 and 5 correspond, I let $\phi_y = 0.5$, as suggested in Taylor (1993), whereas, in the second case, to which Figures 4 and 6 correspond, I let $\phi_y = 0$, as in Lorenzoni (2009).

Figures 3 and 4 illustrate the economy's response to a positive one-standard-deviation purely expectational shock, e, whereas Figures 5 and 6 illustrate the economy's response to a positive one-standard-deviation permanent productivity shock, ϵ. The baseline parametrization appears in Table 1 and is the same as in Lorenzoni (2009). This parametrization implies that the Kalman gain terms, μ and k, are approximately equal to 0.22 and 0.23 respectively, while the relative weight the consumer places on the public signal, θ, is approximately equal

Table 1: Baseline parameters

Inverse Frisch elasticity of labor supply	ζ	0.5
Standard deviation of temporary productivity shock	σ_u	0.15
Standard deviation of permanent productivity shock	σ_ϵ	0.0077
Standard deviation of purely expectational shock	σ_e	0.03

to 0.96 . In all the figures, periods, which appear on the horizontal axis, should be interpreted as quarters.

I assume throughout this part as well as the rest of the analysis that, before any shock hits, the economy is at its steady state. Since permanent productivity, x , evolves as a random walk (see eq. (8)) , the steady state is stochastic and is pinned down by x . For ease of exposition, I will suppress constants. Confirm then that at the steady state $a = x$ and $E^p[a] = E^c[x] = x$, which imply that $y = c = x$, $n = 0$, $\pi = 0$, and $r = i = 0$. With no loss of generality, I further assume that $x = 0$ before any shocks hit.

What distinguishes Figure 3 from Figure 4 , and Figure 5 from Figure 6 , is the response of inflation. In particular, following a positive purely expectational shock, both agents' expectations about permanent productivity increase, and, as a result, so do output, employment and the interest rates for both monetary policy parametrizations considered (see Figures 3 and 4). However, inflation falls in response to a positive purely expectational shock for $\phi_y = 0.5$ (Figure 3) , whereas it rises for $\phi_y = 0$ (Figure 4) . Given that output, employment, the expected real interest rate and the nominal one respond in the same direction under both monetary policy parametrizations, the response of inflation is crucial to the interpretation we should attach to purely expectational shocks. In the case illustrated in Figure 3 ($\phi_y = 0.5$), purely expectational shocks resemble supply shocks, whereas in the case illustrated in Figure 4 ($\phi_y = 0$) purely expectational shocks resemble demand shocks. The latter interpretation is also given in Lorenzoni (2009) for the same choice of parameters. Observe, further, that since agents learn over time, the economy eventually returns to its steady state.

Following a positive permanent productivity shock, both agents' expectations increase yet they underreact. As a result, output behaves likewise, whereas employment and the interest rates fall (see Figures 5 and 6). Once again, the response of inflation depends on the weight put on the output gap. For $\phi_y = 0.5$, inflation rises in response to a positive permanent productivity shock (Figure 5), whereas it falls for $\phi_y = 0$ (Figure 6). Of course, as agents learn, the economy moves toward its new steady state.

5 Monetary policy and expectations

In this section, I explain how different choices of monetary policy parameters lead shocks to have different effects on the economy. I argue in three steps. First, I explain how agents' expectations matter (Section 5.1). Next, I show that consumer and producer expectations have different implications for the economy (Section 5.2). Last, I show how different choices of monetary policy parameters determine which ones eventually prevail (Section 5.3). Additional remarks are collected in Section 5.4.

5.1 How do agents' expectations matter?

First, note that even though prices are flexible, the consumer's expectations about permanent productivity affect output and employment and, as I will now show, they do so in an indirect way. To see this, note that the wedge in agents' expectations about stage-2 inflation, which affects the labor decision and appears on the RHS of eq. (26), is equal to

$$E_t^p[\pi_t] - E_t^c[\pi_t] = E_t^p[\pi_t] - \pi_t = [\kappa_2 \, k\,(1-\theta) + \kappa_3]\,(E_t^p[a_t] - a_t)\,, \tag{28}$$

where the first equality uses the fact that $E_t^c[\pi_t] = \pi_t$, whereas the second uses conjecture (C2) and the fact that

$$E_t^p[\,E_t^c[x_t]\,] = E_t^c[x_t] + k\,(1-\theta)\,(E_t^p[a_t] - a_t)\,. \tag{29}$$

The presence in eq. (28) of coefficient κ_2, which measures the marginal effect of the consumer's expectations on inflation (see conjecture (C2) and eq. (24)), attests that the consumer's expectations affect employment, and hence output, indirectly via inflation. They do so because the consumer has information about permanent productivity, x_t, that the producer does not have. This extra information is current productivity a_t, which serves as a signal to the consumer about permanent productivity, x_t. To the extent that the producer needs to guess inflation, as (26) shows, and to the extent that inflation depends on the consumer's expectations about permanent productivity, $E_t^c[x_t]$, as conjecture (C2) implies and eq. (24) shows, the producer needs to second-guess the consumer and the consumer's expectations matter in this indirect way.

The producer's expectations about current productivity, a_t, matter to the extent that the producer needs to guess the firm's stage-2 revenue, which the firm's profit maximization problem requires him to. They matter in two ways, a direct one and an indirect one. The direct way is due to the producer's attempt to guess the quantity to be produced in stage 2, which the first term on the RHS of eq. (26) captures. The indirect way is via inflation, and is due to the producer's attempt to guess stage-2 prices, which the second term on the RHS of eq. (26) captures.

However, what in fact affects the labor decision, and hence output, via the inflation channel, is what lies in the wedge between the agents' expectations about inflation, $E_t^p[\pi_t] - E_t^c[\pi_t]$, which is given by eq. (28). On the contrary, anything lying in the intersection of the agents' information sets (for example, the producer's expectations) or outside their union (possibly, other non-fundamental shocks) has no effect on output and employment via the inflation channel. The inflation channel is, in turn, controlled by the monetary authority, which the presence of the monetary policy parameters in eq. (24) given (25) attests, and in this way monetary policy comes to the forefront.

5.2 Consumer expectations versus producer expectations

Shocks affect both agents' expectations. The agents' expectations have, however, different implications for the economy. To best illustrate these differences, I will first discuss the effects of purely expectational shocks.

Starting with the consumer's expectations, we can see from eq. (24) that the coefficient attached to them, $1 / \phi_\pi$, is positive, which implies that the consumer's expectations are positively related to inflation. Further, indirectly through inflation, the consumer's expectations are positively related to the labor decision, and hence output, which we can see from eq. (26)

given eq. (28), after letting $\kappa_2 = 1 / \phi_\pi$.

What underlies the effects of the consumer's expectations is a permanent income hypothesis motive, expressed through the Euler equation (20). To see this, consider a positive purely expectational shock. Since a positive purely expectational shock leads the consumer to overestimate the long-run prospects of the economy, consumption smoothing leads to an upward shift in the consumer's current demand, which in turn causes an inflationary pressure, as eq. (24) demonstrates. With prices being flexible, in response to the upward demand shift caused due to the increase in the consumer's expectations, the expected real interest rate, which as I show below coincides with the nominal one, increases one-for-one, just as it would do under complete information (see Section 4.1), that is $\Delta\, r_t \,/\, \Delta\, E^c_t\,[x_t] = 1$. This equiproportional response of the expected real interest rate is what prevents the consumer's expectations from having a direct effect on output and employment.

However, as I argued in Section 5.1 , the consumer's expectations matter indirectly through the producer's expectations about stage-2 inflation; the producer's expectations about stage-2 inflation, in turn, affect the nominal, and consequently the real, wage, causing thereby shifts in supply.

More precisely, were the producer to have complete information, the nominal wage in stage 1 would increase proportionally to the commodity price in stage 2 , and no effect on output and employment would arise via the consumer channel (see Section 4.1). However, when the producer has incomplete information, that is no longer the case. Since the public signal coordinates agents' expectations, the producer becomes overly optimistic too, that is $E^p_t\,[a_t] > a_t$,[6] and consequently overestimates the increase in the consumer's long-run expectations, that is $E^p_t\,[\,E^c_t\,[x_t]\,] > E^c_t\,[x_t]$, which we can confirm from eq. (29). This is translated into the producer overestimating the inflationary pressure to be caused in stage 2 by the consumer's expectations, which we can see from eq. (28) after controlling for κ_3 and letting $\kappa_2 = 1 / \phi_\pi$. As a result, the nominal wage increases more than proportionally relative to the commodity price. This, of course, means that the real wage increases, which causes employ-

[6] Since I assume that the economy is at its steady state before any shocks hit, what is more precisely true for the producer's expectations after a positive purely expectational shock hits is that $E^p_t\,[a_t] = E^p_t\,[x_t] > a_t = x_t$. The first equality follows from (7), whereas the second one follows from the fact that purely expectational shocks do not affect the economy's steady state.

ment to increase and production to expand, partly accommodating, thereby, the consumer's increased demand. However, by causing a shift in supply, the consumer's expectations can indirectly push inflation in a direction opposite to the —above-described—direct one, which is an issue I deal with below. Controlling for that, we can conclude that purely expectational shocks operating via the consumer's expectations cause effects akin to those caused by demand shocks, which Lorenzoni (2009) also demonstrates, although within a New Keynesian framework.

Turning to the producer's expectations, eq. (23) and (24) together show that they push output and inflation in opposite directions, which suggests that the producer's expectations do indeed cause shifts in supply. A sufficient condition for the producer's expectations to be positively related to output, and hence negatively related to inflation, i.e. a sufficient condition for the producer's expectations to cause a downward shift in supply, is

Condition 1. $\phi_\pi > \max\{\frac{\phi_y}{\zeta}, 1\}$.

Condition 1 requires monetary policy to be sufficiently responsive to inflation, with the response to inflation, ϕ_π, being weakly increasing in the response to the output gap, ϕ_y, and weakly decreasing in the inverse Frisch labor elasticity, ζ.

Condition 1 leads the producer's expectations to be positively related to current output because it, effectively, requires the expected real interest rate to be negatively related to the producer's expectations. To see this point, note that

$$\Delta r_t / \Delta E_t^p[a_t] = \Delta i_t / \Delta E_t^p[a_t] = \phi_\pi \kappa_1 + \phi_y \xi_1 = -\xi_1 = -\Delta y_t / \Delta E_t^p[a_t], \qquad (30)$$

where the first equality uses the fact that the expected real interest rate is equal to the nominal one, the second equality uses (18), conjectures (C1) and (C2) and market clearing, the third equality uses the relations among coefficients as they appear on the RHS of eq. (24), and the fourth uses (23).

Eq. (30) shows that the producer's expectations have precisely opposite effects on the expected real interest rate and output, as argued. It is easy to see that coefficient ξ_1, which is given by eq. (25) and shows up in eq. (30), is positive when Condition 1 holds. Hence, under Condition 1, the producer's expectations lower the expected real interest rate and increase output.

An additional benefit Condition 1 brings is that it rules out "sunspot" shocks, eliminating thereby indeterminacies. The indeterminacies it eliminates are nominal: since "sunspot" shocks lie outside both agents' information sets at the time the labor decision is made, they cannot have an effect on employment and output. I will assume throughout this section that Condition 1 holds, with the remaining cases characterized in Appendix B.

To see why the producer's expectations drive output and inflation in opposite directions, note first that the inefficiency caused due to the producer's incomplete information manifests itself as a distortion in the labor optimality condition, causing, therefore, a shift in labor demand. Under Condition 1, following a positive purely expectational shock, the—overly optimistic—producer's expectations shift labor demand positively. This results in a higher equilibrium real wage, which induces the worker to increase his labor supply and production to expand. For a certain commodity demand level, this causes a deflationary pressure since prices need to fall for the commodity market to clear. Summing up, when purely expectational shocks operate via the producer's expectations, they cause effects akin to those caused by supply shocks—interestingly, without affecting the economy's natural level of output—and, under Condition 1, co-monotone ones.

5.3 Demand or supply shocks? The role of monetary policy

Will a demand- or a supply-shock interpretation eventually prevail for purely expectational shocks? With both agents' expectations pushing employment and output in the same direction (under Condition 1), the answer to this question depends on whose effect on inflation dominates, which, as I will now show, depends on how monetary policy is pursued.

To best illustrate the role of monetary policy, let me consider the limit case where $\sigma_u^2 / \sigma_e^2 \to \infty$, which implies for the learning coefficients that $\theta \to 1$ and $\kappa \to \mu$. There are two advantages of considering this limit case. First, it lets purely expectational shocks affect both agents' expectations in exactly the same way at all horizons, which will free the analysis from considerations related to the agents' learning problems. Second, it disentangles the producer from the consumer channel. To see this, recall from the previous section that the consumer's expectations, indirectly through inflation, accentuate the co-monotone supply-shock manifestation of purely expectational shocks. By effectively letting $\theta \to 1$, I disregard aggregate productivity, a_t, in its capacity to serve as an additional signal to the consumer about permanent productivity, x_t. In this way, not only do I mute the indirect effect via inflation of the consumer's expectations on output, which we can see from eq. (26) and (28) together, but I also mute the indirect effect back to inflation caused by the shift in supply that the consumer's expectations invite. To see this last point, note that coefficient κ_1, which by conjecture (C2) measures the marginal effect of the producer's expectations on inflation, indirectly depends on coefficient κ_2, which by conjecture (C2) measures the marginal effect of the consumer's expectations on inflation, which we can confirm from (24) and (25) together. Importantly, however, the direct effect of the consumer's expectations on inflation remains intact. The parametrization in Table 1 implies that the variance of the temporary productivity shock, u_t, is sufficiently small relative to that of the purely expectational shock, e_t, for the approximation I consider here to be a good one. Appendix B characterizes all cases and the intuition below applies to them too.

Further, let me point out the following relations for the inflation coefficients, which follow from eq. (24) and (25):

$$\kappa_1 + \kappa_2 + \kappa_3 = 0 \tag{31}$$

$$\kappa_1 + \kappa_3 = -\frac{1}{\phi_\pi}, \tag{32}$$

where, once again, by conjecture (C2) coefficient κ_1 measures the marginal effect of the producer's expectations on inflation, κ_2 measures the marginal effect of the consumer's expectations on inflation, and κ_3 measures that of productivity.

Since purely expectational shocks affect agents' expectations in the same way, positive purely expectational shocks lower inflation as long as the combined marginal effect on inflation of the agents' expectations is negative, that is when $\kappa_1 + \kappa_2 < 0$, which at the same time is a sufficient condition for output to increase. To see this last point, note that, since κ_2, which is equal to $1 / \phi_\pi$, is positive, $\kappa_1 + \kappa_2$ is negative only if κ_1 is negative. We can see from (23) and (24) that a negative κ_1 implies (and is implied by) a positive ξ_1, where coefficient ξ_1, as we can see from (23), measures the marginal effect of the producer's expectations on output.

Since, when $\kappa_3 > 0$, by eq. (32) we have that $\kappa_1 < -\frac{1}{\phi_\pi} = -\kappa_2$ and vice versa, requiring $\kappa_3 > 0$ is equivalent to requiring $\kappa_1 + \kappa_2 < 0$. What we need then for purely expectational shocks to resemble supply shocks is that the marginal effect of productivity on inflation is positive.

Confirm from (24) and (25) that for $\sigma_u^2 / \sigma_e^2 \to \infty$, coefficient κ_3 tends to

$$\overline{\kappa}_3 = \frac{\phi_y - \zeta}{\phi_\pi (1+\zeta) - (1+\phi_y)} . \tag{33}$$

Under Condition 1, the limit value of κ_3, $\overline{\kappa}_3$, given by (33), which I will henceforth only refer to, is positive if and only if $\phi_y > \zeta$. That is, a value of the monetary policy weight on the output gap, ϕ_y, greater than the inverse Frisch elasticity of labor supply, ζ, implies that purely expectational shocks are negatively related to inflation, causing, therefore, effects akin to those caused by supply shocks.[7] Further and always under Condition 1, $\overline{\kappa}_3$ increases, and, therefore, a supply-shock manifestation of purely expectational shocks becomes more likely, as the weight on the output gap, ϕ_y, increases and the inverse Frisch labor elasticity, ζ, decreases, which I will discuss in turn.

That a greater weight on the output gap, ϕ_y, renders a supply-shock manifestation of purely expectational shocks more likely is a point central to this paper. To see it, note first that by conjecture (C2) and after suppressing constants,

$$E_t^c [\pi_{t+1}] = (\kappa_1 + \kappa_2 + \kappa_3) E_t^c [x_t] . \tag{34}$$

Combining (34) with (31) implies then that expected inflation in the following period is always equal to zero. In turn, this implies that the expected real interest rate coincides with the nominal one, which is given by (18). Effectively, the monetary authority thus sets the equilibrium expected real interest rate. Suppressing constants and using (18) as well as the fact that $y_t^* = a_t$ (see Section 4.1) imply that the expected real interest rate is equal to

$$r_t = \phi_\pi \pi_t + \phi_y (y_t - a_t) . \tag{35}$$

By the Euler equation (20) and market clearing, the expected real interest rate is such that

$$r_t = E_t^c [y_{t+1}] - y_t = E_t^c [x_t] - [\xi_1 E_t^p [a_t] + (1 - \xi_1) a_t] , \tag{36}$$

[7]Away from the limit $\sigma_u^2 / \sigma_e^2 \to \infty$, $\kappa_3 > 0$ requires the weight on the output gap, ϕ_y, to exceed a threshold value lower than the inverse Frisch labor elasticity, ζ, which explains why we get a negative inflation response in the numerical examples in Section 4.2.1 even though $\phi_y = \zeta$ (see also Table 1). Appendix B characterizes all cases away from the limit $\sigma_u^2 / \sigma_e^2 \to \infty$.

where in the second equality I use the fact that $E_t^c\,[y_{t+1}] \,=\, E_t^c\,[x_t]$.

For $\sigma_u^2\,/\,\sigma_e^2 \,\to\, \infty$, Condition 1 implies that the expected real interest rate increases in response to purely expectational shocks. To see this, note that the response of the expected real interest rate to purely expectational shocks is given by

$$\Delta\, r_t\,/\,\Delta\, e_t \,=\, [\phi_\pi\,(\kappa_1 \,+\, \kappa_2) \,+\, \phi_y\,\xi_1]\,k \,=\, (1 \,-\, \xi_1)\,k\,, \tag{37}$$

where the first equality uses (35), conjectures (C1) and (C2), and the learning equations (10) and (11), taking into account the facts that when $\sigma_u^2\,/\,\sigma_e^2 \,\to\, \infty$, $\mu \,\to\, k$ and $\theta \,\to\, 1$; the second equality uses the relations among coefficients as they appear in (23) and (24). It is now easy to confirm that, for $\sigma_u^2\,/\,\sigma_e^2 \,\to\, \infty$ and under Condition 1, coefficient ξ_1 is less than one as claimed.

Next, confirm from (25) that the greater ϕ_y is, the greater is coefficient ξ_1, which measures the marginal effect of the producer's expectations on output. This implies that, under Condition 1, as the weight on the output gap increases, the response of output, and hence of the output gap, to a positive purely expectational shock becomes larger, i.e. the second term on the RHS of (35) increases, whereas that of the expected real interest becomes more muted, i.e. the LHS of (35) increases by less. It has to be then that as long as the weight on inflation satisfies Condition 1 the inflationary pressure caused by purely expectational shocks falls in ϕ_y.

To analyze this—paradoxical, at first glance—general-equilibrium result, note that under Condition 1, κ_3, which measures the marginal effect of productivity a_t on inflation, increases in the weight on the output gap, ϕ_y. Following the analysis in Sections 5.1 and 5.2, this implies that the producer's labor demand shifts up by more in the producer's expectations about stage-2 inflation. A greater upward shift in labor demand drives, in turn, output up by even more and, for the commodity market to clear, the fall in prices needs to be even more pronounced. In other words, under Condition 1, as the weight on the output gap, ϕ_y, increases, the supply effect becomes stronger.

At the same time, the (demand) effect of the consumer's expectations is invariant to changes in ϕ_y. This is because, under the premise that Condition 1 is satisfied, the marginal effect of the consumer's expectations on inflation, which is equal to $1\,/\,\phi_\pi$, is invariant to changes in ϕ_y. As a result, even away from the limit $\sigma_u^2 / \sigma_e^2 \rightarrow \infty$, changes in ϕ_y leave the indirect effect of the consumer's expectations on employment and output via inflation intact too. With the demand effect of the consumer's expectations intact, we therefore reach the conclusion that, under Condition 1, as the weight on the output gap, ϕ_y, increases, a supply-shock manifestation of purely expectational shocks becomes more likely.

Turning to the Frisch labor elasticity, as it increases, that is as ζ falls, coefficient κ_3 increases, which we can also confirm from (33). As a result, the labor demand effect I discussed above becomes reinforced. At the same time, a lower ζ, i.e. a greater Frisch labor elasticity, implies a more responsive labor supply to changes in the real wage, and thus indirectly to shocks to the producer's expectations. Both effects lead then to an increase in coefficient ξ_1, which we can confirm from (25), and a line of thought similar to that above applies.

5.4 Productivity shocks and further remarks

To best illustrate the effects of productivity shocks on inflation, consider a positive shock to the permanent productivity component x_t, ϵ_t. Following a positive permanent productivity shock, both agents' expectations underreact, since agents attribute part of the increase in the public signal to an increase in its noise component. As a result, both demand and supply underreact resulting in a negative output gap and a fall in employment (under Condition 1). This result is in line with the findings of Gali (1999) and Basu et al. (2006) and is also obtained in the more closely related works of Lorenzoni (2009) and Angeletos and La'O (2009). The response of inflation, as before, depends on whether the demand effect of the consumer's expectations or the supply effect of the producer's expectations dominates, which in turn depends on the chosen monetary policy parameters: under Condition 1, for $\phi_y > \zeta$ inflation rises in response to positive permanent productivity shocks, whereas inflation falls for $\phi_y < \zeta$. The intuition is the same as in the case of positive purely expectational shocks, saving, of course, for the fact that agents' expectations underreact after a positive permanent productivity shock. A minor difference, however, arises from the fact that productivity shocks affect output, employment and inflation both directly and indirectly through agents' expectations. Appendix B illustrates this difference, and further makes it clear that permanent productivity shocks and purely expectational shocks of the same sign cannot push inflation in the same direction.

Temporary productivity shocks on impact have effects similar to those caused by permanent productivity shocks. However, from the following period onwards, they serve as purely expectational shocks. Their effects are a mix, then, of those caused by the other two shocks. Hence I will not discuss them separately.

By now, one might wonder what the role of the monetary policy weight on inflation, ϕ_π, is. In fact, general equilibrium effects complicate matters considerably as all three coefficients associated with inflation, κ_1, κ_2, and κ_3, depend on the monetary policy weight on inflation, ϕ_π. This implies that not only the supply effect of the producer's expectations is affected, but also the demand effect of the consumer's expectations. As a result, it is hard to apply a reasoning along the previous lines and I have, therefore, opted to abstract from such considerations. Instead, I only require the monetary policy response to inflation to be sufficiently high in the way Condition 1 prescribes. I further evaluate the role of the monetary policy parameters in the following section.

Let me conclude this section with two more remarks. First, as expected, when the producer's expectations are correct, that is when $E_t^p[a_t] = a_t$, the benchmark complete information-equilibrium allocation prevails, scaled up, however, by the constant term e^{ξ_0}. Second, we can see from eq. (25) that setting $\phi_\pi = 1 - k(1-\theta)$ implies that $\xi_1 = 0$, i.e. it renders the producer's expectations irrelevant for output, which we can see from eq. (23), and, using eq. (4), employment. The same is true in the limit case in which $\phi_y \to \infty$. As I show in the next section, optimal policies assign no role to the producer's expectations, i.e. they imply that $\xi_1 = 0$. The results throughout this section have been the outcome, then, of policies which might be commonly considered, yet they remain suboptimal. One could think of this as the downside of my model, which for expositional reasons has allowed only for one source of inefficiency, namely the producer's incomplete information. In a model with more than one source of inefficiency, for instance along the lines of Lorenzoni (2010) or Angeletos and La'O (2012), purely expectational shocks would survive in constrained-efficient allocations.

6 Welfare

This section discusses welfare and evaluates different specifications of the monetary policy parameters.

Similar to Lorenzoni (2010), the consumer's expected lifetime utility can be expressed as

$$E_{-1}^{c} \sum_{t=0}^{\infty} \beta^{t} \left[\log C_t - \frac{1}{1+\zeta} N_t^{1+\zeta}\right] = \frac{1}{1-\beta} W(\xi_1) + t.i.p. \ , \tag{38}$$

where ξ_1 measures the marginal effect of the producer's expectations on output and is given by eq. (25). All derivations are collected in Appendix A.3, where I further show that the term $W(\xi_1)$ on the RHS of (38), and, hence, welfare, is maximized when $\xi_1 = 0$, that is when the producer's expectations have no effect on output and employment and the complete-information equilibrium allocation is restored. This result should perhaps be unsurprising since the producer's incomplete information is the only source of inefficiency.[8]

Interestingly, in the limit case in which monetary policy responds infinitely aggressively to inflation, that is when $\phi_\pi \to \infty$, we get from (25) that $\xi_1 \neq 0$, that is producer expectations keep having an effect on output and employment. This proves inflation stabilization sub-optimal, a result at odds with Lorenzoni (2009) and, in fact, any work drawing on the workhorse New Keynesian model (for the latter, see Ch. 3 Gali (2008)). As in Angeletos and La'O (2012), incomplete information manifests itself as a real rigidity, which prevents inflation stabilization from leading to output-gap stabilization—i.e. the "divine coincidence" breaks down, an insight also offered in Blanchard and Gali (2007).

More intuitively, at the beginning of each period, the producer faces uncertainty about his stage-2 revenue; by stabilizing inflation, a monetary authority can only eliminate the producer's uncertainty about the price he will sell at in stage 2, while it does nothing to ameliorate the producer's uncertainty about the quantity to be produced. In other words, inflation stabilization eliminates only the inflation channel of expectations, captured by the

[8] One could argue that the inefficiency here is due to agents' asymmetric information. Were agents to have incomplete yet symmetric information, optimality would be restored. This is true however only because preferences are logarithmic in consumption. In more general environments, the producer's incomplete information would suffice. Nevertheless, as I have already argued, it is asymmetric, rather than incomplete yet symmetric, information, together with the presence of a nominal bond market, that enables the monetary authority to have real effects and, potentially, drive the economy to its optimal level. If there were a real bond market in lieu of the nominal bond market, the inflation channel would be absent and replicating the complete-information allocation would not be possible.

second and third terms on the RHS of (19) together (see also (28)), whereas it is entirely silent about the direct, quantity channel of expectations, captured by the first term on the RHS of (19).

Optimal monetary policy manipulates inflation in such a way that the producer, despite his uncertainty about productivity, correctly anticipates his stage-2 revenue. We can see from (25) that this is achieved when the monetary authority sets a weight on inflation equal to $\phi_\pi = 1 - k(1-\theta)$ and this is so for any value of the monetary policy weight on the output gap, ϕ_y. Such a policy, however, is hardly realistic since it requires a monetary authority to be fully aware of the agents' learning problems, let alone that it leads to nominal indeterminacy.

Optimality is also restored in the limit case in which the monetary authority's response to the output gap tends to infinity, i.e. when $\phi_y \to \infty$, with this being so for any value of ϕ_π; anticipating the monetary authority to respond in an infinitely aggressive way to potential deviations in output from its efficient level is what "arrests" the producer's expectations, preventing them from having an effect on output and employment. This result is also in sharp contrast with the policy implications of the New Keynesian paradigm (see Ch. 4 in Gali (2008)). In a sense, the conventional policy implications of the New Keynesian paradigm are here overturned: inflation stabilization is suboptimal, whereas output-gap stabilization is optimal.

Finally, let me discuss how changes in the policy parameters, ϕ_π and ϕ_y, affect welfare, restricting attention only to policies involving values of ϕ_π greater than one. In particular, I will compare the performance of different policies, pinned down by different sets of monetary policy parameters (ϕ_π, ϕ_y), with that of the optimal ones, with the comparison being in consumption equivalence terms. In particular, similar to Lorenzoni (2010), I will look for the value of Δ which is such that

$$E^c_{-1} \sum_{t=0}^{\infty} \beta^t \left[\log\left(1 + \Delta\right) C_t - \frac{1}{1+\zeta} N_t^{1+\zeta}\right] = W^* . \tag{39}$$

W^* denotes the maximized welfare value obtained for the two above-specified policies resulting in $\xi_1 = 0$; Δ denotes the proportional increase in lifetime consumption required to reach the maximum level of welfare, W^*, when a certain policy pinned down by some pair of policy parameters (ϕ_π, ϕ_y) is followed. Further, for a given value of the inverse Frisch labor elasticity, ζ, a greater value of Δ corresponds to a lower level of welfare, which I explicitly show in Appendix A.3.

Figures 7 and 8 illustrate the welfare comparison in consumption equivalence terms.[9] The broad picture that emerges from Figures 7 and 8 is that a monetary authority should be either relatively mild in its response to inflation and the output gap or relatively aggressive.

More precisely, in Figure 7 I explore how the welfare coefficient Δ responds to changes in the monetary policy weight on inflation, ϕ_π, for different, across panels, values of the monetary policy weight on the output gap, ϕ_y. We can see that, for $\phi_y = 0$, as the weight on inflation increases, Δ increases, i.e. welfare falls, whereas the opposite is true for $\phi_y = 0.5$. In the rest of the panels, the same non-monotonic pattern emerges: for relatively low and relatively high values of ϕ_π, Δ is lower, i.e. welfare is higher, than it is for intermediate values of ϕ_π. However, in no case is optimality restored.

In Figure 8, I explore how Δ responds to changes in the monetary policy weight on the output gap, ϕ_y, for different, across panels, values of the monetary policy weight on inflation, ϕ_π. All panels exhibit the same non-monotonic pattern: Δ is relatively higher, hence, welfare is relatively lower, for intermediate values of ϕ_y. Finally, we can confirm that as ϕ_y increases, Δ tends to zero and welfare to its maximum value.[10]

[9] Let me make four comments about Figures 7 and 8. First, in addition to the values of the non-policy parameters which can be found in Table 1, I set $\beta = 0.99$. Second, the values of Δ, which appear on the vertical axis, are multiplied by 100 so that the consumption change corresponding to a welfare difference is expressed in percentage points. Third, for expositional reasons I do not report values of Δ greater than 5 percentage points; instead, I report 5. I do so because around the discontinuity point Δ takes very large positive values tending to infinity. Fourth, the "step" for ϕ_π in Figure 7 and ϕ_y in Figure 8 is 0.1.

[10] To provide an algebraic account of Figure 7, note that for $\phi_y < \zeta - (1+\zeta)\,k\,(1-\theta)$ welfare decreases (Δ increases) in ϕ_π, for $\phi_y \in [\zeta - (1+\zeta)\,k\,(1-\theta)\,,\,\zeta]$ welfare (weakly) increases (Δ weakly decreases) in ϕ_π, whereas for $\phi_y > \zeta$ welfare increases (Δ decreases) when $\phi_\pi > \frac{1+\phi_y}{1+\zeta}$ and decreases (Δ increases) when $\phi_\pi < \frac{1+\phi_y}{1+\zeta}$.

Let me explain further. Maintaining that $\phi_\pi > 1$, we can see from eq. (25) that $\xi_1 > 0$ as long as $\phi_\pi > \max\{1\,,\,\frac{1+\phi_y}{1+\zeta}\}$. Differentiating ξ_1 with respect to ϕ_π yields $\frac{\zeta - \phi_y - (1+\zeta)\,k\,(1-\theta)}{[\phi_\pi\,(1+\zeta) - (1+\phi_y)]^2}$, which is negative as long as $\phi_y > \zeta - (1+\zeta)\,k\,(1-\theta)$. My remarks in the main text follow after taking further into account that $d^2W/d\xi_1^2 < 0$ and $\frac{dW}{d\xi_1}|_{\xi_1=0} = 0$, which Appendix A.3 shows. Last, note that both ξ_1 and $\vartheta\,\xi_1/\vartheta\,\phi_\pi$ exhibit a discontinuity when $\phi_\pi = \frac{1+\phi_y}{1+\zeta}$.

To provide an algebraic account of Figure 8, note that, welfare decreases (Δ increases) in ϕ_y when $\phi_y < (1+\zeta)\,\phi_\pi - 1$ and increases (Δ decreases) when $\phi_y > (1+\zeta)\,\phi_\pi - 1$. Once again, maintaining that $\phi_\pi > 1$, confirm that $\vartheta\,\xi_1/\vartheta\,\phi_y > 0$. This means that whether welfare increases or decreases in ϕ_y depends solely on the sign of ξ_1; hence the remarks in the main text. Once again, note that there is a discontinuity when $\phi_y = (1+\zeta)\,\phi_\pi - 1$ (equivalently, when $\phi_\pi = \frac{1+\phi_y}{1+\zeta}$).

7 Conclusion

Traditionally, purely expectational shocks have been thought to resemble Keynesian demand shocks: when positive, they increase output, employment and inflation. However, such a manifestation seems at odds with the low inflation and the high cyclical employment observed in the US in the second half of the 90s, a period of exuberant optimism. In light of this, I have reconsidered the effects of purely expectational shocks and shown that, indeed, they can resemble demand shocks, as conventionally thought, but they can also resemble supply shocks, as seems to have been the case in the 90s. In the latter case, they increase output and employment—and, unlike typical supply shocks, they do not affect their natural levels—yet they lower inflation. Whether purely expectational shocks resemble demand or supply shocks depends on the monetary policy pursued. And it is precisely this the message that this paper bears.

Recovering purely expectational shocks from the data would in fact shed light on the causes of their seemingly shifting nature. Of course, however, the literature on the identification of purely expectational shocks remains far from settled (e.g. Beaudry and Portier (2006), Blanchard et al. (2012) and Barsky and Sims (2011, 2012)). Further, studying the effects of purely expectational shocks in an environment enriched with credit constraints is a rather natural theoretical extension, not least for the interesting monetary policy implications it could generate. But I shall leave both for future work.

A Omitted derivations

A.1 Kalman filter

Let me start with the consumer's learning process, which is a standard one. Suppose that the consumer's prior for period t permanent productivity, x_t, is

$$x_t \,|\, I^c_{t-1} \sim N(x_{t|t-1}\,, \sigma^2_{x,t-1})\,,$$

where $x_{t|t-1} \equiv E\left[x_t \,|\, I^c_{t-1}\right]$ and $\sigma^2_{x,t-1} \equiv Var\left[x_t \,|\, I^c_{t-1}\right]$.

Upon the arrival of new information, $\{s_t, a_t\}$, the consumer's information set becomes

$I_t^c \,=\, I_{t-1}^c \cup \{s_t, a_t\}$. Given that all the shocks, which are specified in Section 2, are serially uncorrelated, mutually independent, and normally distributed, Bayes' Law implies that the consumer's posterior distribution is

$$x_t \,|\, I_t^c \,\sim\, N\left((1-k_t)\, x_{t|t-1} \,+\, k_t \left[\theta\, s_t \,+\, (1-\theta)\, a_t\right],\, \left(\frac{1}{\sigma_{x,t-1}^2} \,+\, \frac{1}{\sigma_e^2} \,+\, \frac{1}{\sigma_u^2}\right)^{-1} \right),$$

where $k_t \,\equiv\, \frac{\frac{1}{\sigma_e^2} + \frac{1}{\sigma_u^2}}{\frac{1}{\sigma_{x,t-1}^2} + \frac{1}{\sigma_e^2} + \frac{1}{\sigma_u^2}}$ and $\theta \,\equiv\, \frac{\frac{1}{\sigma_e^2}}{\frac{1}{\sigma_e^2} + \frac{1}{\sigma_u^2}}$. Learning coefficient k_t denotes the Kalman gain term, which measures the total conditional precision of new information, $\{s_t, a_t\}$, relative to the total conditional precision of the consumer's information; coefficient θ, which appears in eq. (11), measures the conditional precision of the signal s_t relative to that of the consumer's new information.

Letting $\sigma_{x,t}^2 \,\equiv\, Var\left[x_{t+1} \,|\, I_t^c\right]$, the prior for period $t+1$ permanent productivity, x_{t+1}, is

$$x_{t+1} \,|\, I_t^c \,\sim\, N\left(x_{t+1|t}\,,\, \sigma_{x,t}^2\right),$$

where $x_{t+1|t} \,=\, (1-k_t)\, x_{t|t-1} \,+\, k_t \left[\theta\, s_t \,+\, (1-\theta)\, a_t\right]$ and

$$\sigma_{x,t}^2 \,=\, \left(\frac{1}{\sigma_{x,t-1}^2} \,+\, \frac{1}{\sigma_e^2} \,+\, \frac{1}{\sigma_u^2}\right)^{-1} \,+\, \sigma_\epsilon^2\,. \tag{40}$$

Let σ_x^2 denote the solution (a fixed point) to the Riccati equation (40) (simply set $\sigma_x^2 \,\equiv\, \sigma_{x,t-1}^2 \,=\, \sigma_{x,t}^2$). A solution does not exist in the limit case where $\sigma_e^2 \,\to\, \infty$ and $\sigma_u^2 \,\to\, \infty$. I therefore dismiss this case.

I assume that both agents' prior in period 0 is $x_{0\,|\,-1} \,\sim\, N(0\,,\, \sigma_x^2)$, which implies that both agents' learning problems (see below for the producer's one) are at their steady state when time commences. As a result, the Kalman gain term in eq. (11) is time-invariant and given by

$$k \,\equiv\, \frac{\frac{1}{\sigma_e^2} \,+\, \frac{1}{\sigma_u^2}}{\frac{1}{\sigma_x^2} \,+\, \frac{1}{\sigma_e^2} \,+\, \frac{1}{\sigma_u^2}}\,.$$

Turning to the producer's learning problem, recall from the main text analysis that, by the end of each period, both agents have received the same new information, that is $I_{t-1,2}^p \,=\, I_{t-1}^c$. Given this and their (assumed) common prior in period 0, agents always have the same prior distribution over the following period's permanent productivity, x, which is time-invariant as long as σ_x^2 solves the Riccati equation (40).

The consumer and the producer's information sets differ, however, in stage 1 of each period. In particular, the producer's information set is $I^p_{t,1} = I^p_{t-1,2} \cup \{s_t\}$. Then,

$$x_t \,|\, I^p_{t,1} \sim N\left((1-\mu_t)\, x_{t|t-1} + \mu_t\, s_t \,,\, \left(\frac{1}{\sigma^2_{x,t-1}} + \frac{1}{\sigma^2_e} \right)^{-1} \right) ,$$

where $\mu_t \equiv \frac{\frac{1}{\sigma^2_e}}{\frac{1}{\sigma^2_{x,t-1}} + \frac{1}{\sigma^2_e}}$. To the extent that σ^2_x is time-invariant, μ_t is also time-invariant and given by $\mu \equiv \frac{\frac{1}{\sigma^2_e}}{\frac{1}{\sigma^2_x} + \frac{1}{\sigma^2_e}}$, which is the learning coefficient in eq. (10) .

Along the same lines and using eq. (7) , we can characterize the evolution of the producer's distribution of aggregate productivity, a , over time:

$$a_t \,|\, I^p_{t-1,2} \sim N\left(x_{t|t-1} \,,\, \sigma^2_{x,t-1} + \sigma^2_u \right) \tag{41}$$

$$a_t \,|\, I^p_{t,1} \sim N\left((1-\mu_t)\, x_{t|t-1} + \mu_t\, s_t \,,\, \left(\frac{1}{\sigma^2_{x,t-1}} + \frac{1}{\sigma^2_e} \right)^{-1} + \sigma^2_u \right) \tag{42}$$

$$a_t \,|\, I^p_{t,1} \sim N\left((1-\mu_t)\, x_{t|t-1} + \mu_t\, s_t \,,\, \sigma^2_{x,t} + \sigma^2_u \right) . \tag{43}$$

Once again, as long as σ^2_x solves the Riccati equation (40) , the variance of the producer's (prior or posterior) distribution for a is also time-invariant. To see this, for instance, in the case of the producer's prior, simply compare (41) with (43).

A.2 Equilibria

A.2.1 Complete information [for online publication]

Under complete information, we have that $Y_t = A_t$, which you can confirm from (12) and (14) together. This implies that the Euler equation (13) combined with the nominal interest rate (6) yields

$$\Pi_t^{-\phi_\pi} = E^c_t \left[\frac{1}{\Pi_{t+1}} \frac{A_t}{A_{t+1}} \right] . \tag{44}$$

Conjecture that $\pi_t = \vartheta_0 + \vartheta_1\, E^c_t\,[x_t] + \vartheta_2\, a_t$, where lowercase variables denote the natural logarithm of the respective uppercase ones.

Given this conjecture, the LHS of (44) is equal to

$$e^{-\phi_\pi\,(\vartheta_0\,+\,\vartheta_1\,E_t^c\,[x_t]\,+\,\vartheta_2\,a_t)}\,. \tag{45}$$

Turning to the RHS of (44), first confirm that

$$E_t^c\,[\pi_{t+1}\,+\,a_{t+1}]\;=\;\vartheta_0\,+\,(\vartheta_1\,+\,\vartheta_2\,+\,1)\,E_t^c\,[x_t] \tag{46}$$

$$Var_t^c\,[\pi_{t+1}\,+\,a_{t+1}]\;=\;(\vartheta_1 k+\vartheta_2+1)^2\,\sigma_x^2\,+\,(\vartheta_1 k\theta)^2\,\sigma_e^2\,+\,[\vartheta_1 k(1-\theta)+\vartheta_2+1]^2\,\sigma_u^2\,, \tag{47}$$

where I let $E_t^c\,[\cdot]\;\equiv\;E\,[\cdot\,|\,I_t^c]$ and $Var_t^c\,[\cdot]\;\equiv\;Var\,[\cdot\,|\,I_t^c]$. In eq. (46), I use the fact that $E_t^c\,[x_{t+1}]\;=\;E_t^c\,[x_t]$, whereas in eq. (47) I use (7) and (9), as well as the fact that the shocks, which are specified in Section 2, are mutually independent.

Given that shocks are log-normally distributed, the RHS of (44) is then equal to

$$e^{-\,[\vartheta_0\,+\,(\vartheta_1\,+\,\vartheta_2\,+\,1)\,E_t^c\,[x_t]]\,+\,a_t\,+\,\frac{1}{2}\,\{(\vartheta_1\,k\,+\,\vartheta_2\,+1)^2\,\sigma_x^2\,+\,(\vartheta_1\,k\,\theta)^2\,\sigma_e^2\,+\,[\vartheta_1\,k\,(1-\theta)\,+\,\vartheta_2\,+\,1]^2\,\sigma_u^2\}}\,. \tag{48}$$

Matching coefficients in (45) and (48) yields

$$-\,\phi_\pi\,\vartheta_1\;=\;-\,(\vartheta_1\,+\,\vartheta_2\,+\,1) \tag{49}$$

$$-\,\phi_\pi\,\vartheta_2\;=\;1 \tag{50}$$

$$-\,\phi_\pi\,\vartheta_0\;=\;-\,\vartheta_0\,+\,\frac{1}{2}\,\{(\vartheta_1\,k\,+\,\vartheta_2\,+1)^2\,\sigma_x^2\,+\,(\vartheta_1\,k\,\theta)^2\,\sigma_e^2\,+\,[\vartheta_1\,k\,(1-\theta)\,+\,\vartheta_2\,+\,1]^2\,\sigma_u^2\,\}\,, \tag{51}$$

where σ_x^2 solves the Riccati equation (40).

Solving (49) - (51) yields $\vartheta_1\;=\;\frac{1}{\phi_\pi}$, $\vartheta_2\;=\;-\,\frac{1}{\phi_\pi}$, which appear in Section 4.1, and

$$\vartheta_0\;=\;-\,\frac{1}{2\,(\phi_\pi\,-\,1)}\,\{(\vartheta_1\,k\,+\,\vartheta_2\,+1)^2\,\sigma_x^2\,+\,(\vartheta_1\,k\,\theta)^2\,\sigma_e^2\,+\,[\vartheta_1\,k\,(1-\theta)\,+\,\vartheta_2\,+\,1]^2\,\sigma_u^2\}\,. \tag{52}$$

A.2.2 Incomplete information

Let me start with the optimality conditions. Plug the producer's labor demand condition, (14), into the consumer's labor supply condition, (12), replace for λ_t taking into account that

$\lambda_t = \frac{1}{P_t\,C_t}$, multiply and divide the RHS of the generated expression by P_{t-1}, and confirm that

$$N_t^{\zeta} = \frac{1}{\Pi_t\,C_t}\,\frac{E_t^p\,[\frac{A_t}{C_t}]}{E_t^p\,[\frac{1}{\Pi_t\,C_t}]}\,. \tag{53}$$

Turning to the Euler equation, (13), take into account that the monetary authority sets the nominal bond price according to (6), and confirm that

$$\Pi_t^{-\,\phi_\pi}\left(\frac{Y_t}{Y_t^*}\right)^{-\,\phi_y} = E_t^c\left[\frac{1}{\Pi_{t+1}}\,\frac{C_t}{C_{t+1}}\right]. \tag{54}$$

Note that (53) and (54) correspond to eq. (19) and (20) respectively in the main text. It follows, further, from Section 4.1 that $Y_t^* = A_t$, which I will use from now on.

Let me now post conjectures (C1) and (C2) for log-consumption and log-inflation:

$$c_t = \xi_0 + \xi_1\,E_t^p[a_t] + \xi_2\,a_t \tag{C1}$$

$$\pi_t = \kappa_0 + \kappa_1\,E_t^p[a_t] + \kappa_2\,E_t^c[x_t] + \kappa_3\,a_t\,. \tag{C2}$$

Given that all shocks are normally distributed, I will show that, conditional on the agents' information sets, conjectures (C1) and (C2) imply that both C_t and Π_t are log-normally distributed.

Let me start with the labor optimality condition, (53). Taking technology (in logs $y_t = a_t + n_t$) into account, it can be expressed as follows:

$$e^{\zeta\,(y_t\,-\,a_t)} = e^{-\,(\pi_t\,+\,c_t)}\,\frac{E_t^p\,[e^{a_t\,-\,c_t}]}{E_t^p\,[e^{-\,(\pi_t\,+\,c_t)}]}\,. \tag{55}$$

Next, using market clearing and rearranging terms in (55) yields

$$e^{(1+\zeta)\,c_t\,-\,\zeta\,a_t\,+\,\pi_t} = \frac{E_t^p\,[e^{a_t\,-\,c_t}]}{E_t^p\,[e^{-\,(\pi_t\,+\,c_t)}]}\,. \tag{56}$$

Taking conjectures (C1) and (C2) into account, the LHS of (56) is equal to

$$e^{(1+\zeta)\,\xi_0\,+\,\kappa_0\,+\,[(1+\zeta)\,\xi_1\,+\,\kappa_1]\,E_t^p\,[a_t]\,+\,\kappa_2\,E_t^c\,[x_t]\,+\,[(1+\zeta)\,\xi_2\,-\,\zeta\,+\,\kappa_3]\,a_t}\,. \tag{57}$$

The RHS of (56) is equal to

$$\frac{E_t^p\,\left[e^{-\,\xi_0\,-\,\xi_1\,E_t^p\,[a_t]\,+\,(1\,-\,\xi_2)\,a_t}\right]}{E_t^p\,\left[e^{-\,\{\kappa_0\,+\,\xi_0\,+\,(\kappa_1\,+\,\xi_1)\,E_t^p\,[a_t]\,+\,\kappa_2\,E_t^c\,[x_t]\,+\,(\kappa_3\,+\,\xi_2)\,a_t\}}\right]}\,. \tag{58}$$

Conditional on the producer's information set, $I^p_{t,1} = \Psi_t \setminus \{a_t\}$, the exponent in the numerator of (58) is normally distributed with mean $-\xi_0 + (1-\xi_1-\xi_2)\, E^p_t\,[a_t]$ and variance $(1-\xi_2)^2\,\sigma^2_{p,a}$, where $\sigma^2_{p,a} \equiv Var\,[a_t\,|\,I^p_{t,1}] = \left(\frac{1}{\sigma^2_x} + \frac{1}{\sigma^2_e}\right)^{-1} + \sigma^2_u$ and σ^2_x solves the Riccati equation (40) (see also the analysis in A.1). Then, the numerator of (58) is equal to

$$e^{-\xi_0 + (1-\xi_1-\xi_2)\,E^p_t\,[a_t] + \frac{1}{2}\,(1-\xi_2)^2\,\sigma^2_{p,a}}\,. \tag{59}$$

Before turning to the denominator of (58), note that it follows from (11), given the producer's information set, that

$$E^p_t\,[\,E^c_t\,[x_t]\,] \;=\; (1-k)\,E^c_{t-1}\,[x_{t-1}] + k\,[\theta\, s_t + (1-\theta)\,E^p_t\,[a_t]] \;=\; E^c_t\,[x_t] + k\,(1-\theta)\,(E^p_t\,[a_t] - a_t)\,. \tag{60}$$

Let me now turn to the exponent in the denominator of (58). It is normally distributed and, using (60), its mean is equal to

$$E^p_t\,[-(\pi_t + c_t)] \;=\; -\{\kappa_0 + \xi_0 + [\kappa_1 + \xi_1 + \kappa_2\,k\,(1-\theta) + \kappa_3 + \xi_2]\,E^p_t\,[a_t] + \kappa_2\,E^c_t\,[x_t] - \kappa_2\,k\,(1-\theta)\,a_t\}\,. \tag{61}$$

To find its variance, $Var^p_t\,[-(\pi_t + c_t)]$, where $Var^p_t\,[\cdot] \equiv Var\,[\cdot\,|\,I^p_{t,1}]$, first bring $\pi_t + c_t$ into the following form:

$$\pi_t + c_t \;=\; \kappa_0 + \xi_0 + (\kappa_1 + \xi_1)\,E^p_t[a_t] + \kappa_2\,[(1-k)\,E^c_{t-1}[x_{t-1}] + k\,\theta\,s_t] + [\kappa_2\,k\,(1-\theta) + \kappa_3 + \xi_2]\,a_t\,.$$

It then follows that

$$Var^p_t\,[-(\pi_t + c_t)] \;=\; [\kappa_2\,k\,(1-\theta) + \kappa_3 + \xi_2]^2\;\sigma^2_{p,a}\,. \tag{62}$$

Using (61) and (62), the denominator on the RHS of (58) is then equal to

$$E^p_t\,[e^{-(\pi_t + c_t)}] \;=\; e^{-\{\kappa_0 + \xi_0 + [\kappa_1 + \xi_1 + \kappa_2\,k\,(1-\theta) + \kappa_3 + \xi_2]\,E^p_t\,[a_t] + \kappa_2\,E^c_t\,[x_t] - \kappa_2\,k\,(1-\theta)\,a_t\} + \frac{1}{2}\,[\kappa_2\,k\,(1-\theta) + \kappa_3 + \xi_2]^2\;\sigma^2_{p,a}}\,. \tag{63}$$

Therefore, the RHS of (58) is equal to (simply divide (59) by (63))

$$e^{\kappa_0 + \frac{1}{2}\,\{(1-\xi_2)^2 - [\kappa_2\,k\,(1-\theta) + \kappa_3 + \xi_2]^2\}\,\sigma^2_{p,a} + [1 + \kappa_1 + \kappa_2\,k\,(1-\theta) + \kappa_3]\,E^p_t\,[a_t] + \kappa_2\,E^c_t\,[x_t] - \kappa_2\,k\,(1-\theta)\,a_t}\,. \tag{64}$$

Matching coefficients in (57) and (64) yields

$$\xi_0 \,=\, \frac{1}{2\,(1+\zeta)}\left\{(1-\xi_2)^2 \,-\, [\kappa_2\, k\,(1-\theta) \,+\, \kappa_3 \,+\, \xi_2]^2\right\}\sigma^2_{p,a} \tag{65}$$

$$\xi_1 \,=\, \frac{1 \,+\, \kappa_2\, k\,(1-\theta) \,+\, \kappa_3}{1+\zeta} \tag{66}$$

$$\xi_2 \,=\, \frac{\zeta \,-\, \kappa_2\, k\,(1-\theta) \,-\, \kappa_3}{1+\zeta}\,. \tag{67}$$

Observe that

$$\xi_1 \,+\, \xi_2 \,=\, 1\,, \tag{68}$$

which is a direct consequence of preferences being logarithmic in consumption.

Turning to the Euler equation, (54), it can be expressed as follows:

$$e^{-\,[\phi_\pi\,\pi_t\,+\,\phi_y\,(y_t-a_t)]} \,=\, e^{c_t}\, E^c_t\left[e^{-\,(c_{t+1}\,+\,\pi_{t+1})}\right]. \tag{69}$$

Let me start with the LHS of (69). We can use market clearing and conjectures (C1) and (C2) to express it as

$$e^{-\,[\phi_\pi\,\pi_t\,+\,\phi_y\,(y_t\,-\,a_t)]} \,=\, e^{-\,\{\phi_\pi\,\kappa_0\,+\,\phi_y\,\xi_0\,+\,(\phi_\pi\,\kappa_1\,+\,\phi_y\,\xi_1)\,E^p_t\,[a_t]\,+\,\phi_\pi\,\kappa_2\,E^c_t\,[x_t]\,+\,[\phi_\pi\,\kappa_3\,+\,\phi_y\,(\xi_2\,-\,1)]\,a_t\}}\,. \tag{70}$$

Before continuing, note that

$$E^c_t\left[\,E^p_{t+1}\,[a_{t+1}]\right] \,=\, E^c_t\,[x_t]\,, \tag{71}$$

which in turn follows from (10) and (11).

Turning to the RHS of (69), $c_{t+1} \,+\, \pi_{t+1}$ conditional on the consumer's information set, $I^c_t \,=\, \Psi_t$, is normally distributed with mean

$$E^c_t\,[c_{t+1} \,+\, \pi_{t+1}] \,=\, \xi_0 \,+\, \kappa_0 \,+\, (\xi_1 \,+\, \xi_2 \,+\, \kappa_1 \,+\, \kappa_2 \,+\, \kappa_3)\, E^c_t\,[x_t]\,, \tag{72}$$

where I have used conjectures (C1)-(C2) and eq. (71).

To find its variance, $Var^c_{t+1}\,[c_{t+1} \,+\, \pi_{t+1}]$, where $Var^c_t\,[\cdot] \,\equiv\, Var\,[\cdot\,|\,I^c_t]$, use (7) and (9) to express $c_{t+1} + \pi_{t+1}$ as

$c_{t+1} + \pi_{t+1} =$

$$= \xi_0 + \kappa_0 + [(\xi_1 + \kappa_1)(1-\mu) + \kappa_2(1-k)]E_t^c[x_t] + [(\xi_1+\kappa_1)\mu + \kappa_2 k\theta]s_{t+1} + [\xi_2 + \kappa_2 k(1-\theta) + \kappa_3]a_{t+1}$$

$$= G + [(\xi_1+\kappa_1)\mu + \kappa_2 k + \xi_2 + \kappa_3]x_{t+1} + [(\xi_1+\kappa_1)\mu + \kappa_2 k\theta]e_{t+1} + [\xi_2 + \kappa_2 k(1-\theta) + \kappa_3]u_{t+1},$$

where $G \equiv \xi_0 + \kappa_0 + [(\xi_1 + \kappa_1)(1-\mu) + \kappa_2(1-k)]\,E_t^c[x_t]$ is a term known to the consumer in period t.

Given that shocks are mutually independent, it follows that

$$Var_{t+1}^c[c_{t+1}+\pi_{t+1}] = [(\xi_1+\kappa_1)\mu + \kappa_2 k + \xi_2 + \kappa_3]^2\,\sigma_x^2 + [(\xi_1+\kappa_1)\mu + \kappa_2 k\theta]^2\,\sigma_e^2 + [\xi_2 + \kappa_2 k(1-\theta) + \kappa_3]^2\,\sigma_u^2\,. \tag{73}$$

Hence, using (72) and (73) we get

$E_t^c\left[e^{-(c_{t+1}+\pi_{t+1})}\right] =$

$$= e^{-[\xi_0+\kappa_0+(\xi_1+\xi_2+\kappa_1+\kappa_2+\kappa_3)\,E_t^c[x_t]] + \frac{1}{2}\{[(\xi_1+\kappa_1)\,\mu+\kappa_2\,k+\xi_2+\kappa_3]^2\,\sigma_x^2 + [(\xi_1+\kappa_1)\,\mu+\kappa_2\,k\,\theta]^2\,\sigma_e^2 + [\xi_2+\kappa_2\,k\,(1-\theta)+\kappa_3]^2\,\sigma_u^2\}}\,.$$

Consequently, the RHS of (69) becomes

$$e^{c_t}\,E_t^c\left[e^{-(c_{t+1}+\pi_{t+1})}\right] = e^{-\kappa_0 + \frac{1}{2}\{[(\xi_1+\kappa_1)\,\mu+\kappa_2\,k+\xi_2+\kappa_3]^2\,\sigma_x^2 + [(\xi_1+\kappa_1)\,\mu+\kappa_2\,k\,\theta]^2\,\sigma_e^2 + [\xi_2+\kappa_2\,k\,(1-\theta)+\kappa_3]^2\,\sigma_u^2\}} \times$$

$$\times\; e^{\xi_1\,E_t^p[a_t] - (\xi_1+\xi_2+\kappa_1+\kappa_2+\kappa_3)\,E_t^c[x_t] + \xi_2\,a_t}\,. \tag{74}$$

Matching coefficients in (70) and (74) yields

$$\kappa_0 = -\frac{\phi_y\xi_0 + \frac{1}{2}\{[(\xi_1+\kappa_1)\mu + \kappa_2 k + \xi_2 + \kappa_3]^2\sigma_x^2 + [(\xi_1+\kappa_1)\mu + \kappa_2 k\theta]^2\,\sigma_e^2 + [\xi_2 + \kappa_2 k(1-\theta) + \kappa_3]^2\sigma_u^2\}}{\phi_\pi - 1} \tag{75}$$

and

$$-\left(\phi_\pi\,\kappa_1\,+\,\phi_y\,\xi_1\right)\,=\xi_1 \tag{76}$$

$$-\,\phi_\pi\,\kappa_2\,=\,-\,\left(\xi_1\,+\,\xi_2\,+\,\kappa_1\,+\,\kappa_2\,+\,\kappa_3\right) \tag{77}$$

$$-\left[\phi_\pi\,\kappa_3\,+\,\phi_y\,(\xi_2\,-\,1)\right]\,=\xi_2\,, \tag{78}$$

where ξ_0 is given by (65) .

Coefficients ξ_1 , ξ_2 , κ_1 , κ_2 , κ_3 solve eq. (67) - (68) and (76) - (78) returning the coefficients in eq. (23) - (24) as well as eq. (25) in the main text.

Summing (76) - (78) across sides and using (68) yields

$$\kappa_1\,+\,\kappa_2\,+\,\kappa_3\,=\,0\,, \tag{79}$$

whereas summing (76) and (78) across sides and again using (68) yields

$$\kappa_1\,+\,\kappa_3\,=\,-\,\frac{1}{\phi_\pi}\,, \tag{80}$$

which are equations (31) and (32) respectively in the main text.

Finally, use (68), (76) - (78) and eq. (25) from the main text, and after some manipulation confirm that ξ_0 , which is given by (65), can be expressed in terms of ξ_1 as follows

$$\xi_0\,=\,\frac{(1-\zeta)\,\sigma_{p,a}^2}{2}\,\xi_1^2\,. \tag{81}$$

A.3 Welfare

The expected lifetime utility of the consumer is given by

$$E_{-1}^c\sum_{t=0}^{\infty}\beta^t\left[\log C_t\,-\,\frac{1}{1+\zeta}\,N_t^{1+\zeta}\right]. \tag{82}$$

Let me first take the expectation of period t utility conditional on the consumer's information set in period $t-1$. Using conjecture (C1) and eq. (68), bearing in mind that $E_{t-1}^c\left[x_t\right]\,=\,E_{t-1}^c\left[x_{t-1}\right]$, confirm that

$$E\left[\log C_t\,|\,I_{t-1}^c\right]\,=\,\xi_0\,+\,E_{t-1}^c\left[x_{t-1}\right]. \tag{83}$$

Turning to employment, first express it as

$$n_t \;=\; \xi_0 + \xi_1\,(E_t^p\,[a_t] - a_t) \;=\; \xi_0 + \xi_1\,(1-\mu)\,E_{t-1}^c\,[x_{t-1}] + \xi_1\,(\mu-1)\,x_t + \xi_1\,\mu\,e_t - \xi_1\,u_t\,, \quad (84)$$

where, in the first equality, I use conjecture (C1) and eq. (68), whereas in the second equality I use the producer's learning process (10) as well as (7) and (9). Given that shocks are mutually independent and normally distributed, the conditional distribution of employment is

$$n_t\,|\,I_{t-1}^c \;\sim\; \left(\xi_0\,,\,[\,(\mu-1)^2\,\sigma_x^2\,+\,\mu^2\,\sigma_e^2\,+\,\sigma_u^2\,]\,\xi_1^2\right)\,, \quad (85)$$

where σ_x^2 solves the Riccati equation (40). The mean in (85) follows from (84), the producer's learning process (10), and the fact that $E_{t-1}^c\,[E_t^p\,[a_t]] \;=\; E_{t-1}^c\,[a_t] \;=\; E_{t-1}^c\,[x_{t-1}]$.

Using (83) and (85), it follows that

$$E\,[\log C_t - \frac{1}{1+\zeta}\,N_t^{1+\zeta}\,|\,I_{t-1}^c] \;=\; \xi_0 + E_{t-1}^c\,[x_{t-1}] - \frac{1}{1+\zeta}\,e^{(1+\zeta)\,\xi_0 + \frac{(1+\zeta)^2}{2}\,[(\mu-1)^2\,\sigma_x^2 + \mu^2\,\sigma_e^2 + \sigma_u^2]\,\xi_1^2}\,, \quad (86)$$

where the second term on the RHS of (86) is independent of policy.

To find the unconditional expected utility, use (86) and confirm that

$$E_{-1}^c\,\sum_{t=0}^{\infty}\beta^t\,[\log C_t - \frac{1}{1+\zeta}\,N_t^{1+\zeta}] \;=\; \frac{1}{1-\beta}\,\left[\xi_0 \;-\; \frac{1}{1+\zeta}\,e^{(1+\zeta)\,\xi_0 + \frac{(1+\zeta)^2}{2}\,[(\mu-1)^2\,\sigma_x^2 + \mu^2\,\sigma_e^2 + \sigma_u^2]\,\xi_1^2}\right] + t.i.p.\;\;. \quad (87)$$

Since ξ_0 can be expressed in terms of ξ_1 using eq. (81), the term in square brackets on the RHS of (87) can also be expressed in terms of ξ_1. Let $W(\xi_1)$ which appears on the RHS of eq. (38) in the main text denote it, and confirm that it is equal to

$$W(\xi_1) \;=\; \frac{(1-\zeta)\,\sigma_{p,a}^2}{2}\,\xi_1^2 \;-\; \frac{1}{1+\zeta}\,e^{\frac{(1-\zeta^2)\,\sigma_{p,a}^2}{2}\,\xi_1^2 + \frac{(1+\zeta)^2}{2}\,[(\mu-1)^2\,\sigma_x^2 + \mu^2\,\sigma_e^2 + \sigma_u^2]\,\xi_1^2}\,. \quad (88)$$

Eq. (88) can be simplified as

$$W(\xi_1) \;=\; \frac{(1-\zeta)\,\sigma_{p,a}^2}{2}\,\xi_1^2 \;-\; \frac{1}{1+\zeta}\,e^{\frac{1+\zeta}{2}\,[(1-\zeta)\,\sigma_{p,a}^2 + \gamma\,(1+\zeta)]\,\xi_1^2}\,, \quad (89)$$

where $\gamma \;\equiv\; (\mu-1)^2\,\sigma_x^2\,+\,\mu^2\,\sigma_e^2\,+\,\sigma_u^2$.

I will next show that welfare is maximized only when $\xi_1 \;=\; 0$. To this end, let me first show that $dW(\xi_1)/d\xi_1 \;=\; 0$ only when $\xi_1 \;=\; 0$. Differentiating $W(\xi_1)$, as given by (89), with respect to ξ_1 yields

$$\frac{dW(\xi_1)}{d\xi_1} \;=\; \xi_1\,\{(1-\zeta)\,\sigma_{p,a}^2 \;-\; e^{\frac{1+\zeta}{2}\,[(1-\zeta)\,\sigma_{p,a}^2 + \gamma\,(1+\zeta)]\,\xi_1^2}\,[(1-\zeta)\,\sigma_{p,a}^2 \;+\; \gamma\,(1+\zeta)]\}\,. \quad (90)$$

For $\frac{dW(\xi_1)}{d\xi_1} = 0$, it either has to be that $\xi_1 = 0$ or

$$\xi_1^2 = \frac{2}{(1+\zeta)\left[(1-\zeta)\,\sigma_{p,a}^2 + \gamma\,(1+\zeta)\right]} \log\left[\frac{(1-\zeta)\,\sigma_{p,a}^2}{(1-\zeta)\,\sigma_{p,a}^2 + \gamma\,(1+\zeta)}\right]. \tag{91}$$

The RHS of (91) is always a negative number and, since I restrict attention to real solutions, we can conclude that the only one is $\xi_1 = 0$.

The second-order derivative of $W(\xi_1)$ with respect to ξ_1 is equal to

$$\frac{d^2W(\xi_1)}{d\xi_1^2} = (1-\zeta)\,\sigma_{p,a}^2 - e^{\frac{1+\zeta}{2}\left[(1-\zeta)\,\sigma_{p,a}^2 + \gamma\,(1+\zeta)\right]\xi_1^2}\left[(1-\zeta)\,\sigma_{p,a}^2 + \gamma\,(1+\zeta)\right]\left\{1 + \left[(1-\zeta)\,\sigma_{p,a}^2 + \gamma\,(1+\zeta)\right](1+\zeta)\,\xi_1^2\right\}, \tag{92}$$

which is always negative.

It then follows that welfare is maximized only for $\xi_1 = 0$. Substituting for $\xi_1 = 0$ in (89) yields $W(0) = -\frac{1}{1+\zeta}$. Substituting this in turn in eq. (38) implies that maximum welfare is equal to

$$W^* = -\frac{1}{(1-\beta)\,(1+\zeta)} + t.i.p.\,, \tag{93}$$

which appears on the RHS of eq. (39).

Finally, substituting for W^* in eq. (39) implies that Δ satisfies the following equation:

$$\log\,(1 + \Delta) = -\left(W(\xi_1) + \frac{1}{1+\zeta}\right). \tag{94}$$

Holding ζ constant, it follows that Δ is negatively related to $W(\xi_1)$ and, therefore, welfare.

B Appendix to Section 4.2 [for online publication]

This appendix characterizes the conditions which pin down the business cycle effects of purely expectational and permanent productivity shocks. I ignore, throughout, the possibility of nominal indeterminacies.

B.1 Purely expectational shocks

I will start with the conditions under which purely expectational shocks, e, behave like co-monotone supply shocks—that is when positive, they increase output and employment and they lower inflation.

Since purely expectational shocks do not affect productivity, a_t, and given that labor is the only input used in the production of output (see eq. (4)), purely expectational shocks push output and employment in the same direction.

Positive purely expectational shocks increase output and employment when

$$\xi_1 \, > \, 0 \, , \tag{A}$$

where ξ_1 is given by (25). Condition A follows from eq. (23).

Purely expectational shocks affect inflation through both agents' expectations. They will lower inflation on impact if and only if

$$(1 \, + \, \phi_y) \, \xi_1 \, \mu \, - \, k \, \theta \, > \, 0 \, , \tag{95}$$

and, post-impact, if and only if

$$(1 \, + \, \phi_y) \, \xi_1 \, (1 - \mu) \, (1 - k)^{s-1} \, k \, \theta \, + \, (1 - k)^s \, k \, \theta \, > \, 0 \quad \text{for } s \, \geq \, 1 \, , \tag{96}$$

where s corresponds to period $t + s$. Eq. (95) and (96) follow from eq. (24) and the agents' learning problems, given by eq. (10) and (11).

One can confirm from Appendix A.1 that the agents' learning problems imply that

$$\frac{1 - k}{1 - \mu} \, = \, \frac{k \, \theta}{\mu} \, = \, 1 \, - \, k(1 - \theta). \tag{97}$$

As a result, both (95) and (96) boil down to Condition B:

$$\xi_1 \, > \, \frac{1}{1 \, + \, \phi_y} \, \frac{1 - k}{1 - \mu} \, . \tag{B}$$

Since the term on the RHS of Condition B is positive, Condition B implies Condition A. Condition B is then necessary and sufficient for purely expectational shocks to behave like supply shocks. One can confirm that Condition B boils down to the following requirements:

$$\phi_y \, > \, \frac{1 - k}{1 - \mu} \, (1 + \zeta) \, - \, 1 \quad \text{and} \quad \phi_\pi \, > \, \frac{1 + \phi_y}{1 + \zeta}$$

or

$$\phi_y \, < \, \frac{1 - k}{1 - \mu} \, (1 + \zeta) \, - \, 1 \quad \text{and} \quad \phi_\pi \, < \, \frac{1 + \phi_y}{1 + \zeta} \, .$$

Along the same lines, purely expectational shocks cause effects associated with demand shocks—that is when positive they increase output, employment, and inflation—when

$$\xi_1 > 0 \tag{A}$$

and

$$\xi_1 < \frac{1}{1+\phi_y}\frac{1-k}{1-\mu}, \tag{C}$$

with ξ_1 given by (25). When Condition A holds, positive purely expectational shocks increase output and employment, whereas when Condition C holds positive purely expectational shocks increase inflation.

Condition A requires

$$\phi_\pi > \max\left\{\frac{1+\phi_y}{1+\zeta}, \frac{1-k}{1-\mu}\right\}$$

or

$$\phi_\pi < \min\left\{\frac{1+\phi_y}{1+\zeta}, \frac{1-k}{1-\mu}\right\},$$

where I have again used eq. (97).

Condition C requires

$$\phi_y > \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi < \frac{1+\phi_y}{1+\zeta}$$

or

$$\phi_y < \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi > \frac{1+\phi_y}{1+\zeta}.$$

Conditions A and C together then boil down to

$$\phi_y > \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi < \frac{1-k}{1-\mu}$$

or

$$\phi_y < \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi > \frac{1-k}{1-\mu}.$$

Let $\phi_y^* \equiv \frac{1-k}{1-\mu}(1+\zeta) - 1$. The following proposition summarizes the above results:

Proposition 1. *For $\phi_y > \phi_y^*$, purely expectational shocks cause effects associated with supply shocks when $\phi_\pi > \frac{1+\phi_y}{1+\zeta}$, whereas they cause effects associated with demand shocks when $\phi_\pi < \frac{1-k}{1-\mu}$.*

For $\phi_y < \phi_y^*$, purely expectational shocks cause effects associated with supply shocks when $\phi_\pi < \frac{1+\phi_y}{1+\zeta}$, whereas they cause effects associated with demand shocks when $\phi_\pi > \frac{1-k}{1-\mu}$.

Note that, since $\frac{1-k}{1-\mu} < 1$, it might be that $\phi_y^* < 0$. In that case, the non-negativity constraint on ϕ_y binds, and the second part of Proposition 1 becomes irrelevant.

In the special case in which $\phi_y = \phi_y^*$, it follows from (25) that $\xi_1 = \frac{1}{1+\zeta}$. Since this implies that Condition A is met, positive purely expectational shocks increase output and employment. However, since the agents' effects on inflation precisely offset each other, purely expectational shocks have no effect on inflation, which we can confirm by observing that both conditions B and C are violated. In the special case in which $\phi_\pi = \frac{1-k}{1-\mu}$, it follows from (25) that $\xi_1 = 0$. As a result, positive purely expectational shocks have no effect on output and, since Condition C is satisfied, they are inflationary. The case in which $\phi_\pi = \frac{1+\phi_y}{1+\zeta}$ is undefined.

In the two remaining cases, in particular, when either $\phi_y > \phi_y^*$ and $\frac{1-k}{1-\mu} < \phi_\pi < \frac{1+\phi_y}{1+\zeta}$, or when $\phi_y < \phi_y^*$ and $\frac{1+\phi_y}{1+\zeta} < \phi_\pi < \frac{1-k}{1-\mu}$, Condition C is met but Condition *A* is violated. Then, positive purely expectational shocks lower output and employment and they raise inflation.

A special case. Consider the case discussed in the main text, in which $\sigma_u^2 / \sigma_e^2 \to \infty$. Since, we have, then, that $\theta \to 1$ and $k \to \mu$, the learning coefficients are eliminated from Proposition 1. This case, further, implies that $\phi_y^* \to \zeta$. Hence, Proposition 1 is modified as follows:

Proposition 2 (special case)**.** *When $\sigma_u^2 / \sigma_e^2 \to \infty$,*

- *for $\phi_y > \zeta$, purely expectational shocks cause effects associated with supply shocks when $\phi_\pi > \frac{1+\phi_y}{1+\zeta}$, whereas they cause effects associated with demand shocks when $\phi_\pi < 1$.*
- *for $\phi_y < \zeta$, purely expectational shocks cause effects associated with supply shocks when $\phi_\pi < \frac{1+\phi_y}{1+\zeta}$, whereas they cause effects associated with demand shocks when $\phi_\pi > 1$.*

For the cases not considered in Proposition 2 , check the analysis above.

B.2 Permanent productivity shocks

Suppose that a permanent productivity shock, ϵ_t , hits the economy. Then the impulse responses of output, employment, and inflation are given respectively by

$$\frac{dy_{t+s}}{d\epsilon_t} = 1 - (1-k)^s (1 - \mu) \xi_1 \tag{98}$$

$$\frac{dn_{t+s}}{d\epsilon_t} = \xi_1 \left(\frac{dE^p_{t+s}}{d\epsilon_t} - \frac{da_{t+s}}{d\epsilon_t} \right) = \xi_1 \left(\frac{dE^p_{t+s}}{d\epsilon_t} - 1 \right) \tag{99}$$

$$\frac{d\pi_{t+s}}{d\epsilon_t} = (1-k)^s \left[(1+\phi_y) \xi_1 (1-\mu) - (1-k) \right], \tag{100}$$

where $s \geq 0$ and ξ_1 is given by (25). Eq. (98) and (100) follow, respectively, from (23) and (24) and the agents' learning problems, which are given by eq. (10) and (11). The first equality in (99) uses (23) and technology, given by (4), whereas the second equality in (99) uses the fact that productivity a responds one-for-one to changes in permanent productivity, x .

It follows from eq. (98) - (100) that a positive permanent productivity shock raises output, lowers employment, and raises inflation when

$$\xi_1 < \frac{1}{1-\mu} \tag{D}$$

$$\xi_1 > 0 \tag{A}$$

$$\xi_1 > \frac{1}{1+\phi_y} \frac{1-k}{1-\mu} . \tag{B}$$

Condition D refers to output and follows from (98) and the fact that $1-\mu$ is the maximum value that the term on its RHS $(1-k)^s (1-\mu)$ takes. Condition A refers to employment and follows from (99) and the fact that $\frac{dE^p_{t+s}}{d\epsilon_t} < 1$, whereas Condition B refers to inflation and follows from (100). Recall that Condition B implies Condition A . Hence, conditions D and

B together are necessary and sufficient for positive permanent productivity shocks to raise output, lower employment, and raise inflation.

Condition D requires

$$\phi_\pi > \max\left\{\frac{1+\phi_y}{1+\zeta}\,,\ \frac{\mu + \phi_y + (1-\mu)\,k\,(1-\theta)}{\mu + \zeta}\right\}$$

or

$$\phi_\pi < \min\left\{\frac{1+\phi_y}{1+\zeta}\,,\ \frac{\mu + \phi_y + (1-\mu)\,k\,(1-\theta)}{\mu + \zeta}\right\}.$$

As we have already seen, Condition B requires

$$\phi_y > \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi > \frac{1+\phi_y}{1+\zeta}$$

or

$$\phi_y < \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi < \frac{1+\phi_y}{1+\zeta}.$$

Confirm that $\frac{1+\phi_y}{1+\zeta} > \frac{\mu + \phi_y + (1-\mu)\,k\,(1-\theta)}{\mu + \zeta}$ is true only if $\phi_y < \frac{1-k}{1-\mu}(1+\zeta) - 1$ and the same is true for the opposite inequalities as well as the equality. Then, conditions B and D together require

$$\phi_y > \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi > \frac{\mu + \phi_y + (1-\mu)\,k\,(1-\theta)}{\mu + \zeta}$$

or

$$\phi_y < \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi < \frac{\mu + \phi_y + (1-\mu)\,k\,(1-\theta)}{\mu + \zeta}.$$

Positive permanent productivity shocks raise output and they lower employment and inflation when

$$\xi_1 < \frac{1}{1-\mu} \tag{D}$$

$$\xi_1 > 0 \tag{A}$$

$$\xi_1 < \frac{1}{1+\phi_y}\frac{1-k}{1-\mu}. \tag{C}$$

Observe that Condition C implies Condition D. Hence, conditions A and C together are necessary and sufficient for positive permanent productivity shocks to raise output and lower employment and inflation.

As we have already seen, Condition C requires

$$\phi_y > \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi < \frac{1+\phi_y}{1+\zeta}$$

or

$$\phi_y < \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi > \frac{1+\phi_y}{1+\zeta},$$

whereas Condition A requires

$$\phi_\pi > \max\left\{\frac{1+\phi_y}{1+\zeta}, \frac{1-k}{1-\mu}\right\}$$

or

$$\phi_\pi < \min\left\{\frac{1+\phi_y}{1+\zeta}, \frac{1-k}{1-\mu}\right\}.$$

Conditions A and C then together require

$$\phi_y > \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi < \frac{1-k}{1-\mu}$$

or

$$\phi_y < \frac{1-k}{1-\mu}(1+\zeta) - 1 \quad \text{and} \quad \phi_\pi > \frac{1-k}{1-\mu}.$$

As above, let $\phi_y^* = \frac{1-k}{1-\mu}(1+\zeta) - 1$. The following proposition summarizes the results above:

Proposition 3. *For $\phi_y > \phi_y^*$, positive permanent productivity shocks raise output and inflation and they lower employment when $\phi_\pi > \frac{\mu+\phi_y+(1-\mu)\,k\,(1-\theta)}{\mu+\zeta}$, whereas they raise output and they lower inflation and employment when $\phi_\pi < \frac{1-k}{1-\mu}$.*

For $\phi_y < \phi_y^*$, positive permanent productivity shocks raise output and inflation and they lower employment when $\phi_\pi < \frac{\mu+\phi_y+(1-\mu)\,k\,(1-\theta)}{\mu+\zeta}$, whereas they raise output and they lower inflation and employment when $\phi_\pi > \frac{1-k}{1-\mu}$.

As we have already seen, in the special case in which $\phi_y = \phi_y^*$, it follows from (25) that $\xi_1 = \frac{1}{1+\zeta}$. This implies that conditions D and A are met, whereas both conditions B and

C are violated. As a result, positive permanent productivity shocks increase output, lower employment, and have no effect on inflation. In the special case in which $\phi_\pi = \frac{1-k}{1-\mu}$, it follows from (25) that $\xi_1 = 0$. As a result, positive permanent productivity shocks have no effect on employment and, since conditions D and C are satisfied, they raise output and they lower inflation. The case in which $\phi_\pi = \frac{1+\phi_y}{1+\zeta}$ is undefined. In the special case in which $\phi_\pi = \frac{\mu+\phi_y+(1-\mu)\,k\,(1-\theta)}{\mu+\zeta}$, we get that $\xi_1 = \frac{1}{1-\mu}$. This violates Condition D, but satisfies conditions A and B. As a result, positive permanent productivity shocks have no impact effect on output, however they increase output from the following period onwards, whereas they lower employment and raise inflation.

There are four remaining cases. When either $\phi_y > \phi_y^*$ and $\frac{1+\phi_y}{1+\zeta} < \phi_\pi < \frac{\mu+\phi_y+(1-\mu)\,k\,(1-\theta)}{\mu+\zeta}$, or $\phi_y < \phi_y^*$ and $\frac{\mu+\phi_y+(1-\mu)\,k\,(1-\theta)}{\mu+\zeta} < \phi_\pi < \frac{1+\phi_y}{1+\zeta}$, conditions A and B are satisfied, whereas Condition D is violated. This implies that positive permanent productivity shocks lower employment, raise inflation, and, at least on impact, they lower output.

When either $\phi_y > \phi_y^*$ and $\frac{1-k}{1-\mu} < \phi_\pi < \frac{1+\phi_y}{1+\zeta}$, or $\phi_y < \phi_y^*$ and $\frac{1+\phi_y}{1+\zeta} < \phi_\pi < \frac{1-k}{1-\mu}$, conditions D and C are satisfied, whereas Condition A is violated. Positive permanent productivity shocks raise, then, output and employment and they lower inflation.

The special case revisited. Consider again the case discussed in the main text, in which $\sigma_u^2 / \sigma_e^2 \to \infty$. This case eliminates the learning coefficients from Proposition 3. It, further, implies that $\phi_y^* \to \zeta$. Hence, Proposition 3 is modified as follows:

Proposition 4 (special case)**.** *When* $\sigma_u^2 / \sigma_e^2 \to \infty$,

- *for* $\phi_y > \zeta$, *positive permanent productivity shocks raise output and inflation and they lower employment when* $\phi_\pi > \frac{\mu+\phi_y}{\mu+\zeta}$, *whereas they raise output and they lower inflation and employment when* $\phi_\pi < 1$.

- *for* $\phi_y < \zeta$, *positive permanent productivity shocks raise output and inflation and they lower employment when* $\phi_\pi < \frac{\mu+\phi_y}{\mu+\zeta}$, *whereas they raise output and they lower inflation and employment when* $\phi_\pi > 1$.

For the cases not considered in Proposition 4, check the analysis above.

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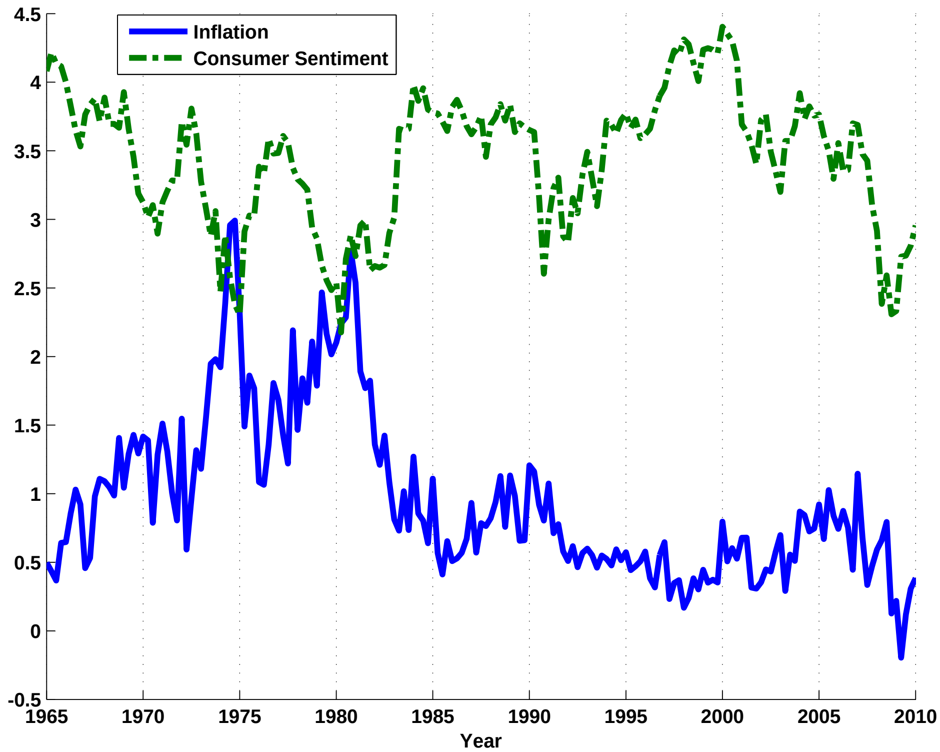
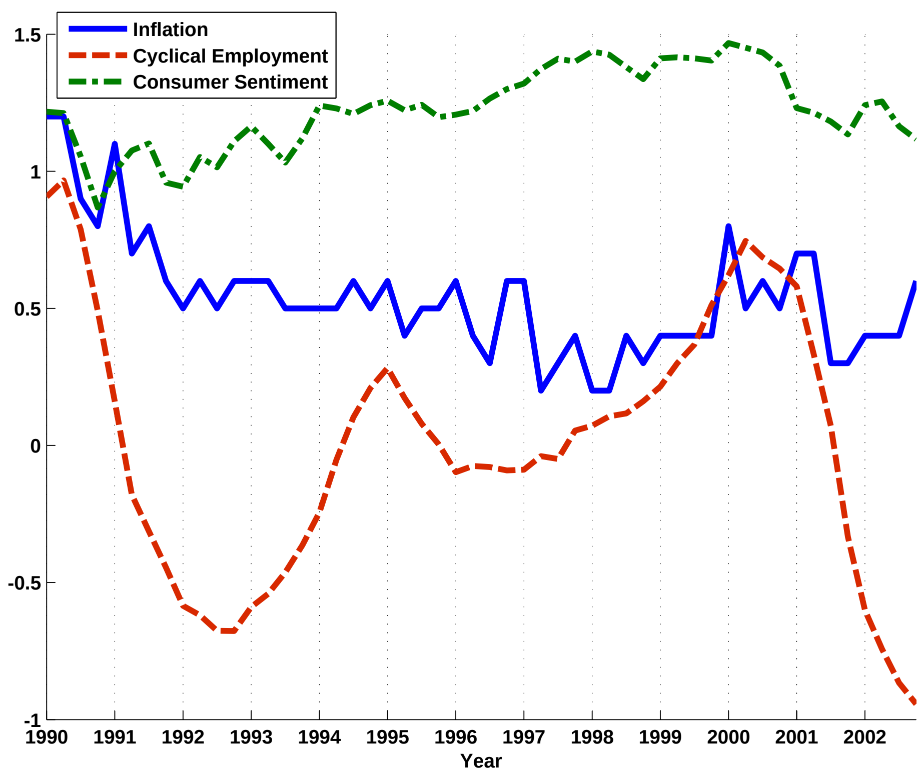
Figure 1: Percent Changes in GDP Deflator and Consumer Sentiment



Notes: The data is collected from the St. Louis Fed, it is US quarterly and spans the period 1965:Q1-2010:Q1. Inflation (solid line) refers to percent changes in the "Gross Domestic Product: Implicit Price Deflator" (series GDPDEF) and is seasonally adjusted. Consumer Sentiment (dot-dashed line) refers to "University of Michigan: Consumer Sentiment" (series UMCSENT1, UMCSENT) and is not seasonally adjusted. For expositional clarity, I have scaled it down by 25.

Figure 2: Percent Changes in GDP Deflator, Cyclical Employment and Consumer Sentiment



Notes: The data is collected from the St. Louis Fed, it is US quarterly and spans the period 1990:Q1-2002:Q4 . Inflation (solid line) refers to percent changes in the "Gross Domestic Product: Implicit Price Deflator" (series GDPDEF) and is seasonally adjusted. Employment refers to "All Employees: Total Nonfarm Employees (Thousands of Persons)" (series PAYEMS) and is seasonally adjusted. It is logged and HP-filtered with penalty 1600 . For expositional clarity, I have scaled up its cyclical component (dashed line) by 50 . Consumer Sentiment (dot-dashed line) refers to "University of Michigan: Consumer Sentiment" (series UMCSENT1, UMCSENT) and is not seasonally adjusted. For expositional clarity, I have scaled it down by 75 .

Figure 3: Impulse responses to a positive purely expectational shock for $\phi_y = 0.5$

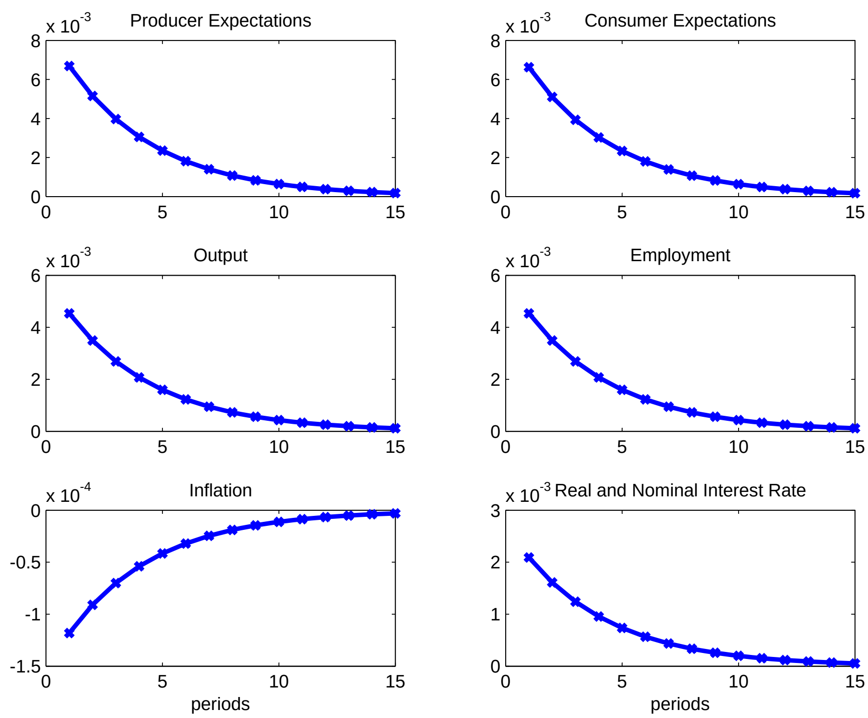


Figure 4: Impulse responses to a positive purely expectational shock for $\phi_y = 0$

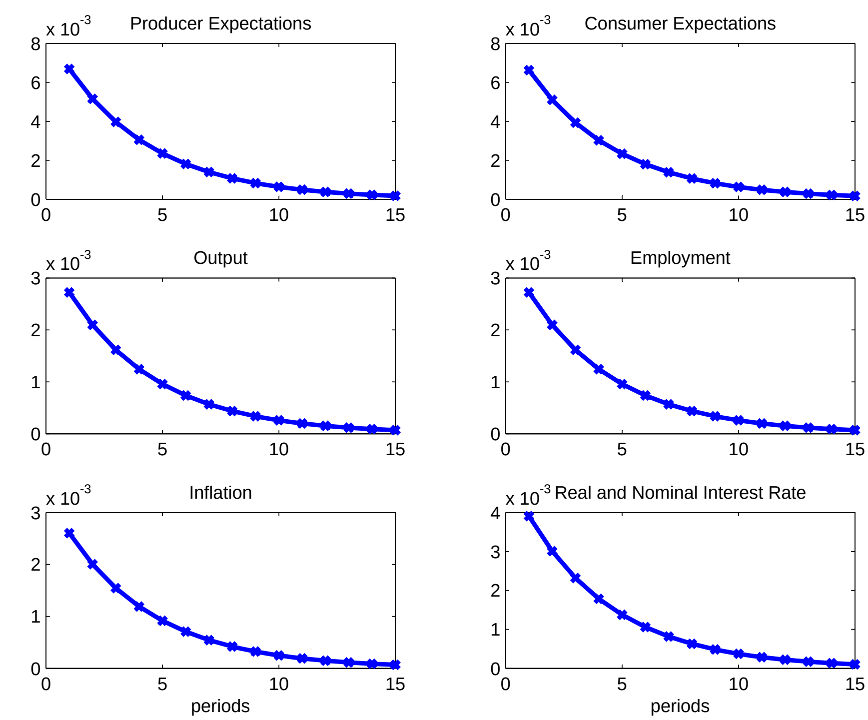


Figure 5: Impulse responses to a positive permanent productivity shock for $\phi_y = 0.5$

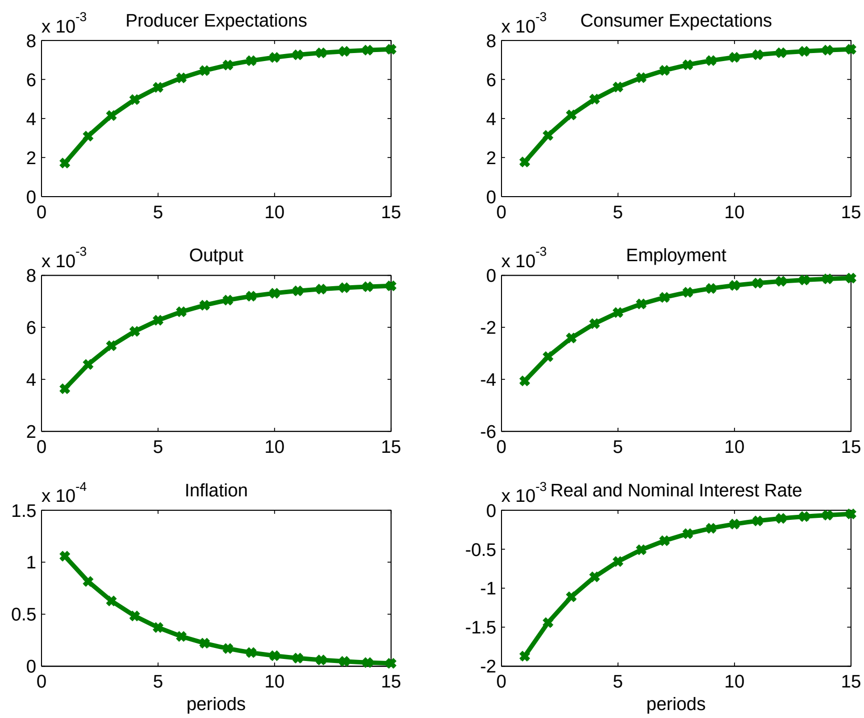


Figure 6: Impulse responses to a positive permanent productivity shock for $\phi_y = 0$

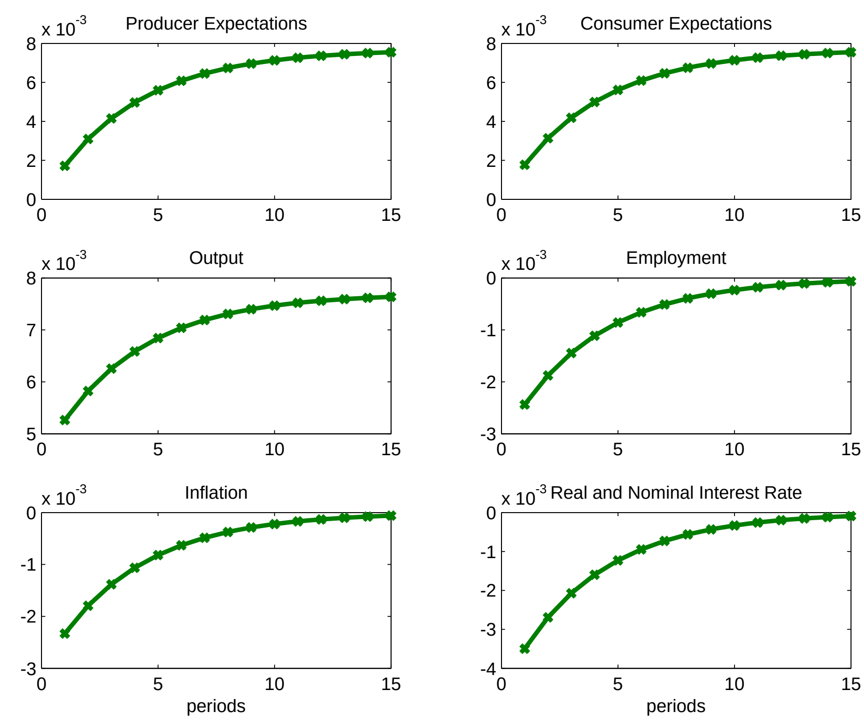


Figure 7: Welfare difference in consumption equivalence terms in response to changes in ϕ_π

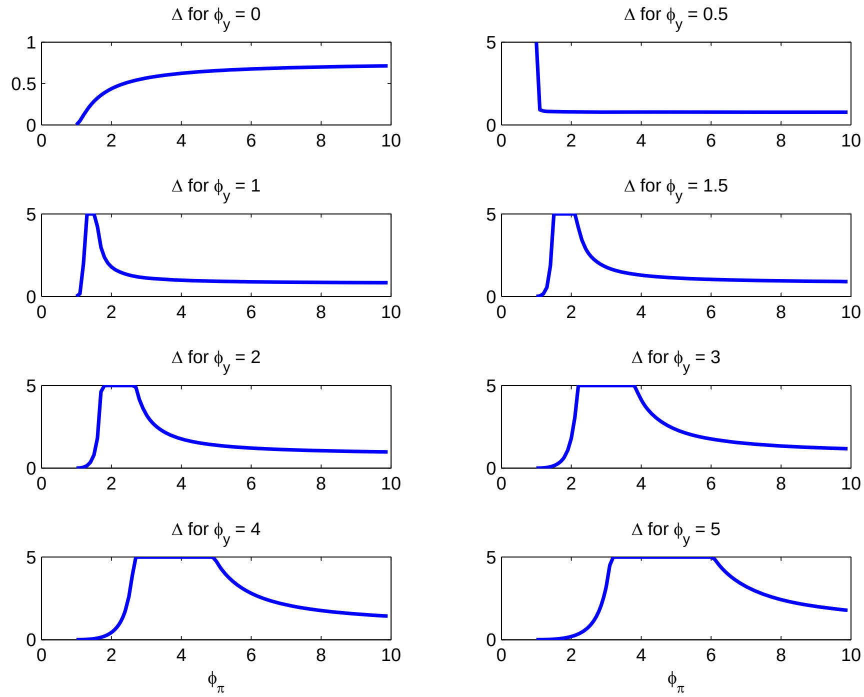


Figure 8: Welfare difference in consumption equivalence terms in response to changes in ϕ_y