

# Can Supply Shocks Be Inflationary with a Flat Phillips Curve?\*

Jean-Paul L’Huillier<sup>a</sup> and Gregory Phelan<sup>b</sup>

<sup>a</sup>Brandeis University

<sup>b</sup>Williams College

Not in standard models. With conventional pricing frictions, imposing a flat Phillips curve also imposes a price level that is rigid with respect to supply shocks. In the New Keynesian model, price markup shocks need to be several orders of magnitude bigger than other shocks in order to fit the data, leading to unreasonable assessments of the magnitude of the increase in costs during inflationary episodes. To account for the facts, we propose a strategic microfoundation of *shock-dependent* price stickiness: prices are sticky with respect to demand shocks but *flexible* with respect to supply shocks. This friction is demand intrinsic, in line with narrative accounts for the imperfect adjustment of prices. Firms can credibly justify a price increase due to a rise in costs, whereas it is harder to do so when demand increases. Supply shocks, including productivity shocks, lead to a flexible price allocation, where inflation rises rapidly and output falls. An output gap ensues only if monetary policy is tightened.

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## 1. Introduction

The recent global rise in inflation presents a challenge for macroeconomics. For over three decades, inflation was virtually a nonstory in advanced economies. Inflation remained incredibly stable, even amidst several large and global recessions and substantial changes in fiscal and monetary policy. One could say that there was a “great moderation” in inflation even as output remained anything but moderate at times. In other words, the relationship between inflation and demand—the so-called Phillips curve (PC)—has been flat, suggesting that demand shocks are not important determinants of variations in inflation.

And yet, inflation globally has recently run at levels not seen in decades. In fact, such rates of inflation have not been observed in developed countries since the Great Inflation of the 1970s. The conjunction of higher inflation with global supply factors, both in the 1970s and in the current episode, is hard to overlook. Indeed, it suggests that supply is a major determinant of inflation.<sup>1</sup>

Thus, our paper is motivated by two empirical facts regarding the dynamics of inflation.

**Fact 1: The Phillips Curve Is Very Flat.** There is a significant body of evidence that for advanced economies the PC is incredibly flat, with a slope that is small or close to zero. Hazell et al. (2022) use cross-sectional data to provide evidence of only a modest flattening of the PC since 1990. According to their findings, the PC has *always* been very flat. Del Negro et al. (2020) find overwhelming evidence in favor of a very flat PC, especially since 1990. Their findings are consistent with other New Keynesian medium-scale DSGE estimations. Both papers estimate slopes on the order of 0.0020.<sup>2</sup>

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<sup>1</sup>Demand factors are also part of the explanation for the recent rise in inflation, especially in the U.S., which enacted a significant post-COVID fiscal package. However, demand alone does not readily explain inflation as a *global* phenomenon, or its magnitude and cross-country synchronization, especially given flat estimates of the PC. More generally, it is well known that in quantitative dynamic stochastic general equilibrium (DSGE) models, cost-push shocks are the main drivers of inflation dynamics.

<sup>2</sup>To be clear, the arguments in our paper do not necessarily rely on the PC being *very* flat. A *moderately* flat PC leads to the same remarks. We are more explicit about this in Section 2.

**Fact 2: Supply Shocks Are Inflationary.** There is mounting evidence that supply-driven sources explain the lion’s share of inflation fluctuations. Känzig (2021) finds that oil news shocks alone explain 50 percent of the forecast error variance decomposition in the U.S. consumer price index (CPI) over previous decades, which provides a lower bound on how much supply disruptions affect inflation. In terms of the current inflation, when considering firm-level pricing decisions in the U.K. following the pandemic, Bunn et al. (2022) conclude that “it is supply side factors that can explain most of the rise in inflation since 2021.” They especially note the role of labor and materials shortages. Similarly, Ball, Leigh, and Mishra (2022) find that energy prices, supply-chain backlogs, and auto-related prices have been most important in explaining U.S. inflation. Papers with more modest findings attribute 40 to 45 percent of the recent inflation to supply shocks (Di Giovanni et al. 2022; Shapiro 2022).

These two facts represent a challenge for standard models. A common misconception is that a flat PC means merely that variations in *demand* do not cause variations in inflation—whereas variations in *supply* could cause inflation. In reality, in standard models, there are no empirically plausible structural shocks that will create significant variations in inflation when the PC slope is close to zero. To understand this point, consider the New Keynesian (NK) family of models. In these models, because of the flatness of the PC, the degree of price stickiness required to fit the data is very high (Del Negro et al. 2020; Hazell et al. 2022). The “Calvo fairy” does not visit firms very frequently. But then, supply shocks of a reasonable size cannot be inflationary, since the fairy *also* needs to visit firms for them to adjust prices when cost-push shocks hit. Using a simple calibration based on mainstream estimates, we find that in order to generate a 1 percentage point (pp) increase in inflation, firms’ desired markups need to increase by 500 percent. NK models cannot deliver realistic inflation volatility unless one is willing to accept the existence of cost-push shocks several orders of magnitude larger than other structural shocks.<sup>3</sup> Importantly, this is *not* a problem specific to the post-COVID episode, but it is general empirical

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<sup>3</sup>A steeper PC reduces this required markup increase somewhat, but not to reasonable levels.

failure that arises when attempting to matching postwar data. Indeed, this observation is a variation on the critiques in Chari, Kehoe, and McGrattan (2009) and Bils, Klenow, and Malin (2012), but here we show that the flat PC is the fundamental cause of the implausible price markup shocks that they highlight.<sup>4</sup>

Our main goal, therefore, is to present a theory that can address both Facts 1 and 2. As we observed, the data suggest that firms treat demand and supply disturbances distinctly when setting prices. In other words, the evidence points toward *shock dependence* in price adjustment.<sup>5</sup> We provide a microfounded model of shock-dependent price stickiness in which inflation can be entirely rigid with respect to demand shocks and yet entirely flexible with respect to supply shocks. In the model, firms face no exogenous or technological constraints to adjust prices, such as menu costs or the blessing of a Calvo fairy. The proposed microfoundation is based on a strategic interaction between firms and consumers. The strategic environment we consider can simultaneously produce a very flat PC while also producing significant inflation in response to supply disturbances.

Besides delivering novel insights on firms' optimal pricing behavior, shock dependence also offers a theory of cost-push shocks. First, in general equilibrium, our model delivers a PC with a slope that depends on the degree of nominal rigidity with respect to output gaps, which are determined by the demand side of the economy, and can be zero. Second, in our model, the PC's *intercept* is determined by the supply side of the economy. This is important: the PC can flexibly shift up and down with supply shocks *and*, at the same time, be entirely flat. This is impossible in NK models, because there the intercept is fixed at zero when the PC is flat (see Section 2). Put differently, in our model the PC features a cost-push shock that moves inflation one-to-one even when the PC is perfectly flat, whereas the structural PC in the NK model does not. This is because the Calvo fairy does not touch firms at all for a perfectly flat PC, and hence cost-push shocks do not pass through at all to

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<sup>4</sup>As discussed below, standard pricing frictions—such as Calvo, Taylor, menu, or Rotemberg costs—all suffer from the same issue. The reason is the common feature of treating rigidity with respect to supply and demand symmetrically.

<sup>5</sup>Shock-dependent price stickiness is related to what Ghassibe and Zanetti (2022) call state-dependent fiscal multipliers, in which the size of the multiplier depends on whether recessions are driven by demand or supply shocks.

inflation. Third, in our model, we can use a productivity shock as our canonical supply shock, though our results apply to any type of shock that affects firms' marginal costs. In the standard NK model, productivity shocks do not operate as cost-push shocks; generating cost-push shocks requires a shock to another parameter, namely shocks to desired markups. In sum, different from the NK model, our model offers the possibility of *structural* cost-push shocks that move marginal costs in a simple and natural way.

We model a strategic firm-consumer interaction where firms are better informed than consumers about aggregate conditions. This can be motivated by the view that firms are sophisticated players in many markets, or by the view that firms observe a wider range of transactions in the market they supply. The ability to aggregate information puts firms in a privileged position. For instance, firms may possess superior information about the state of aggregate demand (given their observation of quantities sold) or about costs (given their observation of the cost of inputs). As a result of their superior information, firms optimally evaluate the implications of alternative pricing strategies. The formal macroeconomic setup builds on the models of L'Huillier (2020) and L'Huillier and Zame (2022), with the addition of supply shocks. The central idea of this setup is that prices may convey information possessed uniquely by the firm, and consumers' perceptions of alternative prices influence their purchase decision and ultimately firms' profits.<sup>6</sup>

More specifically, in the model, there are two aggregate shocks: a shock to aggregate nominal demand and a shock to aggregate supply. A nominal demand shock determines whether it is a "good time to buy" (or not), and a supply shock is real shock that determines the level of firms' real marginal costs. A fraction of consumers have less information than firms about the realization of the shocks. Firms are monopolists, and set prices. We use standard preferences and assumptions about agent rationality, and solve for a perfect Bayesian equilibrium of the game played between firms and consumers. Firms'

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<sup>6</sup>L'Huillier (2020) shows that this model delivers hump-shaped dynamic responses of both output and inflation, even in the absence of bells and whistles. Thus, these models also deliver realistic predictions for the propagation of shocks. L'Huillier and Zame (2022) show that the price stickiness result is robust to the consideration of optimal mechanisms and contract setting.

prices may, therefore, provide information about aggregate demand and supply conditions. Crucially, though, information about aggregate demand is payoff relevant for consumers, whereas information about firms' costs is not (since costs affect firm profits directly, but not consumer utility). As a result of this strategic distinction, we find that prices can be *endogenously* sticky with respect to demand shocks. However, firms always pass on cost increases to consumers (for any degree of information asymmetry). Prices adjust flexibly to supply shocks.<sup>7</sup>

Put differently, demand changes lead to a strategic friction, and so sticky prices emerge naturally as a credible firm strategy. But supply disruptions do not lead to a strategic friction, and therefore prices are flexible with respect to supply shocks. When both shocks arise simultaneously, the price can fully adjust to the supply shock but not adjust to the demand shock, an extreme case of shock dependence in price adjustment. Due to the differing firm incentives that arise depending on the type of shock, adjustment itself differs. Our model can simultaneously produce a flat PC and large responses of inflation to supply disturbances. This result helps rationalize the empirical evidence by Känzig (2021), Ball, Leigh, and Mishra (2022), and Bunn et al. (2022), among others, which favors the interpretation that supply shocks are responsible for the recent inflation. This is precisely what our model predicts.

Supply shocks shift the position of the PC and lead to a flexible price allocation in the absence of central bank intervention. Following a supply disruption, a rise in the price level simply reflects firms' lower productivity or higher costs of production. Higher prices result in lower demand and output, but no output gap ensues. There is also no price dispersion. If the central bank raises interest rates to lower inflation, then monetary policy will generate a negative demand shock, thus causing a negative output gap. The reason is,

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<sup>7</sup>As a matter of fact, our model is one where firms would prefer to communicate that price increases are due to cost increases ("we are raising our prices because our costs have increased") rather than demand increases ("we are raising our prices because our product has become more popular"). Whereas this is not exactly how firms behave in the model, it is a useful thought to get intuition. It is worth noting that Blinder et al. (1998) provide survey evidence that "when costs increase, [...] customers normally tolerate price increases" (see Table 7.3, p. 157).

again, that the price level is sticky with respect to demand shocks. However, with a flat PC, the negative output gap will have limited success in bringing down inflation. This type of conclusion highlights the importance of explicitly microfounding the sources of the price friction. Our paper underlines the usefulness of capturing the shock-dependent response of inflation commanded by the data when assessing the implications of alternative monetary policy rules.

**Related Literature.** There is a classic literature providing evidence that the firm-customer relation is what limits price adjustment, suggesting that nominal price-setting frictions are demand based (Hall and Hitch 1939; Okun 1981; Kahneman, Knetsch, and Thaler 1986; Greenwald and Stiglitz 1989; Blinder 1991). Blinder et al. (1998) provide survey evidence that when asked to explain their reluctance to increase prices after an increase in costs, firms' managers usually answer that "price increases cause difficulties with customers." For recent work on the topic, see Rotemberg (2005), Nakamura and Steinsson (2011), Dupraz (2017), and Gilchrist et al. (2017). To the best of our knowledge, none of these works share the prediction that prices are sticky to demand shifts but flexible to supply shifts.

A recent number of papers argues that fairness concerns and other behavioral features constitute bases for price rigidity in the survey evidence cited above (Rotemberg 2005, 2011; Eyster, Madarasz, and Michailat 2021). Our line of work provides a theoretical foundation for this type of rigidity in a model with standard assumptions on agents' rationality and preferences. In our model, firms behave strategically when setting prices, considering how consumers may perceive a posted price. The key insight is that the degree of information among consumers may limit price adjustment, when firms are strategic and may be tempted to stimulate demand.

There is a robust literature that attempts to reconcile the New Keynesian framework with the data. The first major challenge is explaining (or reinterpreting) the so-called missing inflations during the Great Recession. It constitutes an anomaly within the standard paradigm.

Several factors have been considered to explain (or reinterpret) these phenomena, such as inflation expectations (Jorgensen and Lansing 2019), online retail (Cavallo 2018), and globalization (Forbes 2019). See L'Huillier and Schoenle (2023) for related

evidence of the link between the frequency of price adjustment and the inflation target.

There are laudable contemporaneous attempts within the literature to improve the ability of the NK model to match inflation dynamics—for example, by taking seriously nonlinearities or how belief formation affects the PC (e.g., Ascari and Fosso 2021; Ascari, Bonomolo, and Haque 2022; Harding, Lindé, and Trabandt 2022, 2023). This literature moves the NK model in the right direction because it reconciles the observed flat PC with the rise in inflation observed after 2021:Q2. In this vein, our contribution is targeted at delinking the tight restriction that symmetric rigidities impose within the NK model. We argue that incorporating shock-dependent price rigidities (with respect to supply and demand disturbances) will provide macroeconomists with the ability to better account for the facts.

## 2. Motivation: No Cost-Push Inflation with a Flat Phillips Curve in the New Keynesian Model

The structural New Keynesian Phillips curve (NKPC) is generally written as

$$\hat{\pi}_t = \beta \mathbb{E}_t[\hat{\pi}_{t+1}] + \kappa \hat{x}_t + \lambda \hat{z}_t, \quad (1)$$

where  $\hat{\pi}_t$  denotes inflation,  $\hat{x}_t$  denotes the output gap,  $\hat{z}_t$  denotes a *structural* cost-push shock, and  $\beta$ ,  $\kappa$ , and  $\lambda$  are parameters.  $\beta$  is the discount factor.  $\kappa$ , the slope of the PC, measures the sensitivity of inflation to output gap fluctuations.  $\lambda$  measures the sensitivity of inflation to cost-push shocks. ( $\kappa$  and  $\lambda$  are related by a proportionality coefficient.)

**Empirical Evidence on  $\kappa$  and  $\lambda$ .** Estimates of *both*  $\kappa$  and  $\lambda$  are very small. Hazell et al. (2022) estimate the slope of the PC in the cross-section of U.S. states using two distinct instrumental variables (IV) for aggregate demand (which, in their model, causes unemployment to fluctuate). The first IV is given by lagged unemployment and nontradable prices, which delivers an estimate of  $\kappa = 0.0062$ . The second IV captures tradable demand spillovers as an instrument for demand (unemployment). Based on the idea that supply shocks in tradable sectors will differentially affect demand



in nontradable sectors, they estimate  $\kappa = 0.0062$  using their preferred specification (remarkably, both strategies deliver the same estimate). They also directly estimate  $\lambda = 0.0020$  (see Table C.2 in their paper). Del Negro et al. (2020) use an alternative empirical strategy. They employ a medium-scale DSGE model with real rigidities, sticky wages, and financial frictions. Their mean posterior estimates of  $\lambda$  are 0.015 pre-1990 and 0.0015 post-1990. In sum, their empirical estimates imply a value of  $\lambda$  that is no more than 0.015 in general and as small as 0.0015 post-1990.

**Structural Cost-Push Shocks, Reduced-Form Cost-Push Shocks, and Inflation.** The canonical supply shocks are productivity shocks. In the NK model, negative supply shocks are inflationary because they create a positive output gap. However, productivity shocks cannot create significant inflation because  $\kappa$  is almost zero. This is one reason why the NK literature has adopted other shocks, such as a shocks to markups, as the standard inflationary supply shocks.

A common step in the literature consists of rescaling markup shocks, especially in practice when it comes to medium-scale DSGE estimation. Defining the *reduced-form shock*  $\hat{\nu}_t \equiv \lambda \hat{z}_t$ , we can write the NKPC in a form similar to Equation (1):

$$\hat{\pi}_t = \beta \mathbb{E}_t[\hat{\pi}_{t+1}] + \kappa \hat{x}_t + \hat{\nu}_t. \quad (2)$$

While variations in  $\hat{x}_t$  cannot create inflation because  $\kappa$  and  $\lambda$  are so small, variations in the *reduced-form shock*  $\hat{\nu}_t$ , which affects inflation one-for-one, can.

This last step is problematic when it comes to empirics. Matching the empirical behavior of inflation requires ascribing a great deal of volatility to the  $\hat{\nu}_t$  term. But the structural shock is the change in underlying costs  $\hat{z}_t$ . If  $\lambda = 0.0020$ , which is the direct estimate from Hazell et al. (2022), or, rounding up the post-1990 mean posterior estimate from Del Negro et al. (2020) at 0.0015, then generating a 1 percent variation in  $\hat{\nu}_t$  requires a change in  $\hat{z}_t$  by  $1\%/0.002 = 500\%$ . If steady-state markups are 12.5 percent, then a shock of this size requires that desired markups increase to 575 percent, an implausibly large structural shock.<sup>8</sup> A 1 pp increase in inflation due to a

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<sup>8</sup>The shock is applied to the gross markup, thus the gross markup with the shock is  $1.125(500\%) + 1.125 = 6.75$ , which corresponds to a net markup of

cost-push shock requires implausibly large structural shocks. The standard normalization is far from innocuous. It amounts to an important rescaling of the markup shock.

The severity of this problem can also be seen by considering an alternative reduced-form way to write the cost-push shock  $\hat{\nu}_t \equiv \kappa(\hat{y}_t^e - \hat{y}_t^n)$ , where  $\hat{y}_t^e$  and  $\hat{y}_t^n$  represent the efficient and natural levels of output, respectively (Galí 2015). With  $\kappa = 0.0062$ , generating a 1 percent cost-push shock requires the natural rate of output to differ from the efficient level by  $1\%/0.0062 = 161\%$ . The welfare implications of these cost-push shocks would, therefore, be enormous. Both in the 1970s and in the recent episode, inflation has increased by much more than 1 pp and the effect of supply shocks on inflation has been large. Therefore, the observed large increases in inflation aggravate the issue raised by the usual normalization of cost-push shocks in the NK model.

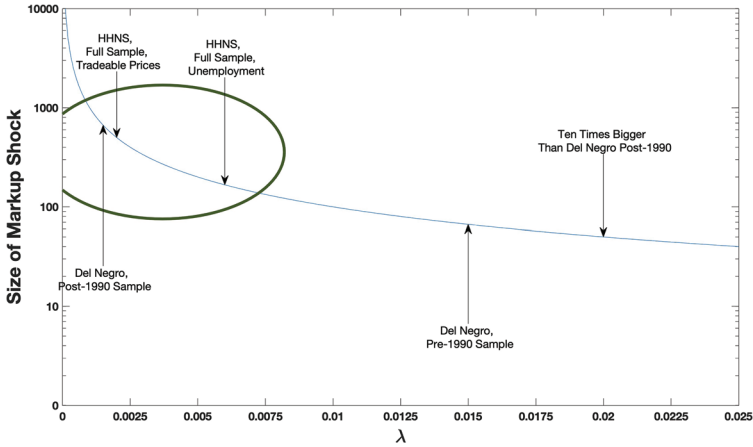
Our reading of the literature indicates that, while this point is understood—for instance, by Chari, Kehoe, and McGrattan (2009) and Bils, Klenow, and Malin (2012)—the novelty here is to point out that this is a direct *economic* implication of the type of pricing friction present in NK models, where the same degree of price rigidity applies to all shocks, symmetrically. In order to generate a very flat PC, the model needs to be parameterized with very high degrees of rigidity. The immediate implication of this is, clearly, that markup shocks cannot easily generate inflation volatility.

Over time this problem has become acute, as there is some evidence that the PC may have flattened over the years (Del Negro et al. 2020). Some commentators have suggested that the very recent inflation episode is evidence that the PC has steepened again or exhibits nonlinearities. We are very cautious about overturning careful empirical work based on decades of data and thoughtful identification strategies on the basis of one episode of high inflation. However, even if the slope has increased, say, tenfold, the problem remains: structural shocks would need to be at least 50 percent to generate a 1 percent reduced-form shock, or 250 percent to generate a 5 pp

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575 percent. Since the gross markup is  $\frac{\epsilon}{\epsilon-1}$ , where  $\epsilon$  is the elasticity of substitution, this means that the markup shock corresponds to an elasticity drop from its steady-state value of 9 to 1.17. If the markup shock is taken literally in terms of log deviations, then the increase in the gross markup is even larger ( $1.125e^5$ ).

**Figure 1. Markup Shock for 1 pp Increase in Inflation (log scale)**



increase in inflation. In terms of output levels, the natural and efficient levels would still have to differ by 16 percent and 81 percent respectively to generate those reduced-form shocks.

These conclusions are robust in several dimensions. First, to visualize the robustness of our conclusion to alternative values of the slope of the PC, Figure 1 presents the size of the markup shock needed to generate a 1 pp increase in inflation as a function of  $\lambda$ . The y-axis, which presents the size of the shock, is plotted on a logarithmic scale. The dark-green circle surrounds the most plausible values, based on the Del Negro et al. (2020) and Hazell et al. (2022) papers. For these values, the conclusion is that the size of the markup shock is orders of magnitude larger than the effect on inflation. Therefore, even important increases in  $\lambda$ , such as Del Negro et al. (2020)'s pre-1990 estimate or an estimate 10 times larger than their baseline, do not affect our conclusion that the markup shock needs to be very large.<sup>9</sup> Second, real rigidities or sticky wages could, in theory, reconcile a very low  $\kappa$  with a larger  $\lambda$ . As we discuss in Appendix C, the empirical evidence does not favor this possibility.

<sup>9</sup>In a similar vein, taking into consideration housing services could lead to a higher slope (Hazell et al. 2022) but would not affect our conclusions.

In the next section, we argue that this observation suggests considering price-setting frictions with shock-dependent price rigidities: firms' prices are flexible with respect to supply shocks but simultaneously sticky with respect to demand disturbances. In essence, we propose a model in which  $\lambda$  and  $\kappa$  are not directly related, and one can have a very low  $\kappa$  without requiring a very low  $\lambda$ , with plausible empirical relationships between marginal costs and output gaps.

### 3. Strategically Sticky Prices

We now present the microfoundation for shock dependence in price adjustment. The framework we use is parallel to L'Huillier (2020), with the addition of shocks to supply. For clarity, we first consider the strategic behavior of firms in response to demand shocks and then consider their behavior in response to supply shocks. Finally, we consider both shocks simultaneously. Crucially, in our model, we can use a productivity shock as our canonical supply shock, though our results apply to any type of shock that affects firms' marginal costs.

For ease of exposition, we use a simple two-period, partial equilibrium model. The same points could be made in a more complicated infinite-horizon, general equilibrium model (Appendix F).

#### 3.1 Model Setup

There are two dates, the present and the future, which we interpret as the short run and the long run. In the short run, production and trade in goods markets will be subject to frictions; in the long run, agents have exogenous endowments and trade will be frictionless. All that follows is common knowledge.

**Setup: Geography, Agents, and Markets.** The economy is populated by firms, consumers, and a central bank (CB). At each date, firms and consumers trade in a market for a single good. Short-run markets are decentralized; we formalize this by positing a continuum of islands, each served by a single monopolistic firm and populated by a continuum of consumers. Long-run markets are centralized; we formalize this by positing that all consumers trade endowments in a Walrasian, perfectly competitive, market. We

denote decentralized-market variables in lowercase and centralized-market variables in uppercase. Thus, the good in the present is  $c$  and its price is  $p$ ; the good in the future is  $C$  and its price is  $P$ . We normalize the long-run price to  $P = 1$ . There is a short-run bond market with nominal interest rate  $i$ . We posit a cashless economy in which the CB sets the nominal interest rate. In this partial equilibrium setup, there is no labor supply.

**Aggregate State.** In the present, there is uncertainty about the aggregate state of the economy, denoted by  $\{\xi, z\}$ . The aggregate state captures two dimensions of the economy: aggregate demand pressure  $\xi$  and aggregate supply pressure  $z$ . We assume that the two shocks are orthogonal.

We model aggregate demand as determined by a shock to consumers' discount factor. For simplicity, we assume there are only two possible states, low and high, that occur with equal probability. The discount factor defines the consumer discount rate, denoted by  $\rho$ . Demand in the present will be high when consumers' discount rate is high, and therefore  $\rho_H$  corresponds to the high state and  $\rho_L$  corresponds to the low state, with  $\rho_H > \rho_L$ .

The central bank sets the nominal interest rate, denoted  $i_s$ . Because monetary policy affects aggregate demand, we define a net demand shock, or *demand pressure*, denoted by  $\xi$ . This is given by the two realizations:

$$\frac{1 + \rho_L}{1 + i_L} \equiv \xi_L < \xi_H \equiv \frac{1 + \rho_H}{1 + i_H}.$$

Thus, the shock  $\xi$  captures changes in demand pressure caused by the changes in subjective and market discount factors. Let  $\xi_0$  denote the harmonic mean of  $\xi_L, \xi_H$ , that is,  $\xi_0 \equiv \left[ \frac{1}{2} (\xi_L^{-1} + \xi_H^{-1}) \right]^{-1}$ . We normalize  $\xi_0 = 1$ . The significance of  $\xi$  will be clear when we study the consumer problem below.<sup>10</sup>

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<sup>10</sup>Similar to L'Huillier (2020), it is possible to model the nominal demand shock as a shock to the future price level or, equivalently, as a shock to money supply (that implies a proportional adjustment of prices in the long run). However, in this paper we prefer the current formulation in terms of shocks to future marginal utility in order to allow for a standard specification of monetary policy in the quantitative application below.

Aggregate supply pressure determines firms' real marginal costs, denoted by  $z$ . We define *supply shocks* as exogenous changes in marginal costs. We can think of variations in  $z$  as capturing any variations in marginal costs, such as changes in the prices of intermediate goods or energy (like oil), changes in wages driven either by shocks to labor supply or shocks to wage bargaining, or changes in productivity. Importantly, and different from the NK model, whether the change in  $z$  represents an efficient or inefficient variation is not critical for our analysis. We develop this point more deeply in Section 3.5. We use the terms "supply shocks" and "cost shocks" interchangeably. For simplicity, we suppose that the supply shock can take only two values, high  $z_H$  and low  $z_L$ , that occur with equal probability, with expectation  $\mathbb{E}[z] = z_0$ .

We suppose the economy begins at  $\{\xi_0, z_0\}$  and then experiences a shock in the present.

**Islands: Consumer Types and Firms.** Each island is populated by a continuum of consumers of total mass one and a single monopolistic firm. There are two types of consumers: Insiders (informed consumers)  $\iota \in I$  and Outsiders (uninformed consumers)  $o \in O$ . Insiders are perfectly informed about the state; Outsiders are uninformed about the state but know the probability distribution and may draw inferences from the price set by the firm with which they trade.

The fraction  $\alpha \in [0, 1)$  of Insiders on a particular island varies across islands. We use this source of heterogeneity to allow for distinct patterns of price adjustment across islands. We assume the distribution of  $\alpha$  is given by a cumulative distribution function (CDF)  $F$  whose support is not a singleton and has the property that  $\lim_{\alpha \rightarrow 1} F(\alpha) = 1$ . That is, the fraction of islands on which all consumers are Insiders is 0. Define  $\alpha_0, \alpha_1$  to be the lower and upper limits of the support of  $F$ :

$$\begin{aligned}\alpha_0 &= \sup\{\alpha \in [0, 1] : F(\alpha) = 0\} \\ \alpha_1 &= \inf\{\alpha \in [0, 1] : F(\alpha) = 1\}.\end{aligned}$$

Hence,  $[\alpha_0, \alpha_1]$  is the smallest closed interval that contains the support of  $F$ :  $\alpha_0$  is the fraction of Insiders on the least-informed island, and  $\alpha_1$  is the fraction of Insiders on the most-informed island. By assumption, the support of  $F$  is not a singleton, so  $\alpha_0 < \alpha_1$ .

Each island is inhabited by a single monopolistic firm with real marginal cost  $z$ . All firms know the true state and the fraction of Insiders on their island; firms can condition the price they set on the true state. The assumption that Insiders and firms know the true state is just a convenient abstraction of the idea that they are better informed than Outsiders. L’Huillier (2020) motivates the assumption of informed firms by the existence of a “time 0” where firms observe market transactions.

**Consumer Problem.** We index a typical consumer by  $j$ . To simplify notation, we drop state subscripts when not absolutely necessary. Consumers have a real endowment  $E$  in the future and receive firm profits  $d$  in the present.

All consumers have the same quasi-linear utility function  $U(c, C) = (c - c^2/2) + \beta\theta C$ , where  $\beta$  is a constant satisfying  $0 < \beta < 1$  and  $\theta$  is a random variable embodying the discount factor shock. Equivalently, one can think about  $\theta$  as shocks to future marginal utility, an interpretation convenient for preserving imperfect information in the short run. The shock  $\theta$  is meant as a proxy for the many possible reasons that the present would, all else equal, be a “good” or “bad” time for consumers to spend, e.g., strong labor markets, rosy expectations of income growth, etc.<sup>11</sup> Outsiders are uncertain about the value of their future nominal marginal utility. This potentially unknown shock to future preferences captures uncertainty about future demand in a similar way that preference shocks in Diamond and Dybvig (1983) capture unforeseen liquidity needs.

Consumer  $j$  solves

$$\begin{aligned} \max_{c, C} \quad & \mathbb{E}_j[(c - c^2/2) + \beta\theta C] \\ \text{s.t.} \quad & pc + QC = d + QE, \end{aligned}$$

where  $\mathbb{E}_j[\cdot]$  is consumer  $j$ ’s expectation operator at the present (conditioned on information available to that consumer),  $p$  is the

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<sup>11</sup> We do not take the shock literally, but rather suppose that it captures the various economic mechanisms that would make nominal consumption relatively attractive in the present relative to the future. Quadratic utility is needed for analytical tractability since it generates linear demand functions. We can derive qualitatively similar results with general utility functions.

nominal price the consumer faces in the short run for goods, and  $Q \equiv \frac{1}{1+i}$  is the nominal price for bonds. The natural rate of interest  $\rho$  is defined implicitly by the equation  $\beta\theta \equiv \frac{1}{1+\rho}$ .<sup>12</sup>

**Firm Problem.** Each island is populated by a single monopolistic firm. We assume that firms produce the consumption good at a nominal marginal cost  $z\xi$ , with  $z_H < 1$ . Let  $y(p)$  denote the consumer demand at the island given a price  $p$ . The firm profit given price  $p$  is  $(p - z\xi)y(p)$ . Note that demand shocks mechanically affect firms' nominal marginal costs, reflecting general equilibrium adjustments under flexible product markets. One microfoundation that generates this relationship would be a working capital assumption: the timing convention that production costs (wages or intermediate goods) are paid at the end of the first period, and therefore the production cost is the discounted value of the price level in the future; see Appendix F for a formalization.

**Perfect Information Benchmark.** The full-information benchmark is straightforward. Consumer  $j$ 's optimal short-run demand is

$$c^* = 1 - p \frac{\beta\theta}{Q} = 1 - p \frac{1}{\xi}.$$

Note that when  $\xi$  is high, demand in the present is high, and thus  $\xi$  acts as a demand shifter. The optimal price is  $p^* = \frac{\xi(1+z)}{2}$ , flexible with respect to both shocks, and the *natural level of output*, denoted  $y^n$ , is

$$y^n = \frac{1-z}{2}.$$

Notice, output is fixed regardless of the demand shifter  $\xi$  (the nominal demand shock is neutral). However, the supply shock  $z$  does

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<sup>12</sup>In order to substantiate the assumption that some consumers may have imperfect information about their future marginal utility (equivalently, the aggregate discount factor), Appendix E.1 offers a more involved model where all consumers perfectly know their future marginal utility (or discount factor), but they are subject to a signal extraction problem with aggregate and idiosyncratic shocks. Both models lead to the same conclusions. In addition, Appendix E.2 offers a microfoundation of our future marginal utility shock based on shocks to future endowments, which then affect the realization of future marginal utility. In that case, one can interpret this shock as mimicking imperfect information about future income, similar to the work by Lorenzoni (2009).



affect the natural level of output. (There remains a monopoly distortion at the natural level of output.)

### 3.2 Demand Shocks and Strategically Sticky Prices

Here, we suppose that firms' real marginal cost is fixed at  $z$  and we consider how variations in demand  $\xi$  affect the slope of the PC. We denote the state (demand) by  $s$ .

**Equilibrium Short-Run Prices.** With imperfect information, consumer  $j$ 's optimal short-run demand is

$$c^* = 1 - p \mathbb{E}_j \left[ \frac{\beta \theta_s}{Q_s} \right] \equiv 1 - p \mathbb{E}_j \left[ \frac{1}{\xi_s} \right].$$

Hence,  $\mathbb{E}_j \left[ \frac{1}{\xi_s} \right]$  is the expectation of the net demand shock, determining whether demand in the present is strong or weak.

When information is not perfect and consumers and firms behave strategically, we must ask whether the full-information price is consistent with equilibrium in the implicit game between the firm and the consumers. Because the full-information price varies with the state, we refer to the full-information price as the flexible price, with  $p_s$  defined by  $p^*$  above. The question is whether adherence to the flexible price is optimal for the firm. For example, would the firm prefer to charge the price  $p_H$  even when the true state is  $L$ ? It is possible that the firm will be tempted to charge  $p_H$  instead of  $p_L$  to extract more rents, especially if many consumers are Outsiders. The question is whether the firm can, by posting the high price  $p_H$ , convince the uninformed consumers that it is indeed a "good time to buy." If this were an equilibrium, the firm would be using the price increase to stimulate total demand: posting a high price means it is a good time to buy, which makes the informed consumers pay higher nominal prices for the same real quantity (hence shifting the demand curve outward). Crucially, high prices are not necessarily credible: firms are always tempted to stimulate demand (even when it is not a good time to buy). Clearly, such behavior cannot lead to an equilibrium with rational consumers: higher prices would fail to stimulate demand, and lead to lower profits. Hence, a strategic friction emerges.

In this context, the appropriate notion of equilibrium is perfect Bayesian equilibrium (PBE), which requires consumers to use Bayes's rule in equilibrium (and hence understand rationally the implications of firms' equilibrium behavior). We should ask whether the flexible price is consistent with some PBE. This guarantees that the firm does not deviate from  $p_L$  in state  $L$ . Lemma 1 provides a sharp answer to this question.

LEMMA 1 (PBE with Flexible Prices). *The flexible price  $\{p_s\}$  is consistent with some PBE if and only if  $\alpha \geq \bar{\alpha} \equiv \frac{1-z}{(\xi_H/\xi_L)(1+z)-2z}$ .*

When the fraction of Insiders is high enough, the flexible prices are in fact consistent with an equilibrium. As a note,  $\bar{\alpha}$  is decreasing in  $z$ , and  $\bar{\alpha} = \frac{\xi_L}{\xi_H}$  when marginal costs are zero.

The opposite end of the spectrum from the flexible price is a price schedule that is the same in both states of the world—a *sticky price*. For simplicity, we focus on a particular sticky price, denoted  $p_0$ , which is a natural choice for two reasons: it is the price that would be optimal in the absence of a shock (i.e., if  $\xi = \xi_0$ ), and it is the price that would be optimal if no consumers were informed ( $\alpha = 0$ ). Of course, we require that  $p_0$  be consistent with some PBE as well; Lemma 2 provides a complete characterization.

LEMMA 2 (PBE with Sticky Prices). *The sticky price is  $p_0 \equiv \xi_0(1+z)/2$ . For  $z$  sufficiently small,  $p_0$  is consistent with some PBE if  $\alpha \leq \bar{\alpha}$ .*

When the fraction of Insiders is low enough, the sticky price is in fact consistent with an equilibrium. Echoing what we said before, if too many consumers know the state, the sticky price is not a sustainable strategy. Finally, whenever *both* the sticky price and the flexible price schedule are consistent with PBE, the firm strictly prefers the flexible price schedule.<sup>13</sup>

**Aggregate Prices and the Phillips Curve.** On each island, the firm chooses between the sticky price  $p_0$  and the flexible price

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<sup>13</sup>We require that  $z$  not be so large because  $\xi$  affects both demand and *nominal* costs, and thus a low  $z$  ensures that this latter effect does not dominate.

schedule  $\{p_s\}$  defined above, subject to the requirement that whatever it chooses should be consistent with PBE and deliver the higher profit. On islands where  $\alpha \geq \bar{\alpha}$ , the firm will choose the flexible price schedule  $\{p_s\}$  and demand will not depend on the state (it will be at the natural level of output  $y^n$ ). On islands where  $\alpha < \bar{\alpha}$ , the firm will choose the sticky price  $p_0$  and demand will depend on the state. Keeping in mind that the Insiders know the state but the Outsiders do not, we see that on these islands demand will be

$$y_s(p_0) = \alpha \left[ 1 - p_0 \frac{1}{\xi_s} \right] + (1 - \alpha) \left[ 1 - p_0 \frac{1}{\xi_0} \right].$$

(The first term is the demand of the Insiders, who know the true state; the second term is the demand of the Outsiders, who do not know the true state.) Having defined the local prices and demands in each state  $s$ , aggregate prices  $\bar{p}_s$  and demands  $\bar{y}_s$  in state  $s$  are

$$\bar{p}_s = \int_0^{\bar{\alpha}} p_0 dF(\alpha) + \int_{\bar{\alpha}}^1 p_s dF(\alpha), \quad (3)$$

$$\bar{y}_s = \int_0^{\bar{\alpha}} \left[ \alpha \left( 1 - p_0 \frac{1}{\xi_s} \right) + (1 - \alpha) y^n \right] dF(\alpha) + y^n [1 - F(\bar{\alpha})]. \quad (4)$$

The baseline aggregate price used to define the PC is therefore given by  $\bar{p}_0 = \xi_0(1 + z)/2$ , which is the flexible price given the baseline demand shock  $\xi_0$ , and baseline output is  $\bar{y}_0 = y^n$ . Define the *output gap* as the difference between actual and natural output:  $\bar{x}_s \equiv \bar{y}_s - y^n$ . We define the PC to be the line crossing the two points  $(\bar{x}_s, \bar{p}_s)$  and  $(0, \bar{p}_0)$ . We define the *slope*  $\bar{\kappa}$  of the PC to be the ratio:

$$\bar{\kappa} = \frac{\bar{p}_s - \bar{p}_0}{\bar{x}_s}.$$

From Equations (3) and (4), the slope of the PC is

$$\bar{\kappa} = \xi_s \left( \frac{1 - F(\bar{\alpha})}{\int_0^{\bar{\alpha}} \alpha dF(\alpha)} \right). \quad (5)$$

The price difference is the difference in the flexible prices for the measure of firms using flexible prices. The output difference is the

difference in demand from informed consumers on islands with sticky prices.

The PC flattens (i.e., the slope  $\bar{\kappa}$  decreases) as the size of demand shocks decreases, and it becomes perfectly flat (i.e.,  $\bar{\kappa} = 0$ ) in the limit as  $\xi_H \rightarrow \xi_L$ . Small net demand shocks could reflect, for example, a hawkish central bank. We can state the following result.

**LEMMA 3 (Flat Phillips Curve Under Demand Shocks).** *The Phillips curve is flat,  $\bar{\kappa} = 0$ , if demand shocks are sufficiently small, i.e., if  $\xi_H$  is sufficiently close to  $\xi_L$ .*

To understand the mechanism underlying Lemma 3, note that, on all islands where sticky prices prevail, the PC (for those islands) is horizontal (has slope 0): prices are independent of the state but demands are not. Conversely, on all islands where flexible prices prevail, the PC (for those islands) is vertical (has slope  $+\infty$ ): prices depend on the state but demands do not. As net demand shocks decrease, more firms choose sticky prices and fewer firms choose flexible prices. Fundamental demand shocks can still be large as long as the central bank policy offsets the shock (i.e., raising rates in response to positive shocks; see L’Huillier, Phelan, and Zame 2022).

### 3.3 Supply Shocks and Strategically Flexible Prices

We now consider the consequences of a supply shock that directly affects firms’ costs. Recall that the problem of standard models is having robust responsiveness of inflation to empirically plausible supply shocks when the PC is very flat. To simplify exposition, we suppose there are no demand shocks for now ( $\xi = \xi_0 = 1$ ). We denote the state (supply) by  $\varsigma$ .

Let  $\lambda$  denote the marginal costs elasticity of aggregate prices. The response of inflation to supply shocks is given by

$$\lambda \equiv \frac{\partial \bar{p}/p_0}{\partial z_\varsigma/z_0}.$$

As we supposed with the demand shock, the firm and the Insiders know the value of  $z_\varsigma$ , but the Outsiders do not. By standard arguments, consumers only care about the price they pay and about their own demand (the realization of the demand shock). Therefore,

firms have no incentive to stimulate demand when costs increase. Whether or not consumers know the costs, when costs are high, firms earn higher profits by charging higher prices; when costs are low, firms earn higher profits by charging lower prices. Profit-maximizing prices do not depend on consumers knowing firms' costs. In this case, there is actually *no strategic friction*, and the equilibrium is given by the solution to the standard monopoly problem. When costs rise, prices rise and consumers demand less. Nonetheless, higher prices are necessary because of the higher costs. In sum, it is a straightforward result that the firm will always choose a flexible price (for any fraction of Outsiders).

**PROPOSITION 1 (Flexible Prices with Inflationary Shocks).** *When the economy experiences shocks to the marginal cost  $z_\zeta$ , all firms choose a flexible price  $p_\zeta = \frac{1+z_\zeta}{2}$ , output is at potential  $y^n$ , and  $\lambda = 1$ , for all  $\alpha$ .*

A few remarks are in order. First, in this model, in which prices are endogenously sticky for strategic reasons, demand shocks can lead to price stickiness, while supply shocks will never lead to price stickiness. This means that the responsiveness of prices to cost shocks is completely different from the responsiveness to demand shocks.

Second, even though costs are not payoff relevant for consumers, for consistency with the previous section, in this PBE consumers can be allowed to learn the realization of costs from the price (although one can construct the same equilibrium without this requirement, since  $z_\zeta$  is irrelevant to consumers). Different from the case of demand shock, firms are not subject to an incentive-compatibility constraint (there is no strategic friction between firms and consumers).

Third, because the equilibrium is a flexible price equilibrium, there is no price dispersion. There is a distortion caused by the monopolistic markup, and therefore equilibrium is inefficient, but the inefficiency is not caused by sticky prices as is the case in the NK model, for example. In the next section, we look at the dynamic responses to the shock for different central bank response rules. We show that if Outsiders do not know how the central bank will respond to an inflationary shock, then firms may adjust their prices

in response to the inflationary shock but not in response to the central bank.

### 3.4 Demand and Supply Shocks

We now introduce both demand and supply shocks, denoting as before the state of demand by  $s$  and state of supply by  $\varsigma$ . The following result characterizes equilibrium prices. It characterizes the consequences of shock dependence when both shocks hit the economy.

**PROPOSITION 2 (Demand and Supply Shocks).** *When the economy experiences both demand and supply shocks and  $\alpha \leq \bar{\alpha}_H \equiv \frac{1-z_H}{(\xi_H/\xi_L)(1+z_H)-2z_H}$ , aggregate prices are flexible with respect to the supply shock but sticky with respect to the demand shock. Firms post  $p_{0,\varsigma} = \frac{1+z_\varsigma}{2}$ .*

In our shock-dependent model, equilibrium prices are sticky with respect to the demand shock (and therefore firms *do not* condition their prices on it), but equilibrium prices are flexible with respect to the supply shock (and therefore firms *do* condition their prices on it). Stickiness with respect to demand is evident in the lack of dependence of  $p_{0,\varsigma}$  on  $\xi_s$  (recall the normalization of the demand shocks term,  $\xi_0 = 1$ ). Flexibility with respect to supply is evident in the dependence of  $p_{0,\varsigma}$  on the  $z_\varsigma$  term.

We have already noted that firms have no strategic incentive to misrepresent the realization of  $z_\varsigma$ , and that remains true here. The firm can convey information about the shock  $z_\varsigma$  without conveying information about the demand shock  $\xi$ .

**The Phillips Curve and Supply-Driven Inflation.** How sticky aggregate prices are with respect to demand depends on the fraction of firms choosing sticky prices. The aggregate price level given cost  $z$  and demand  $\xi$  is therefore

$$\begin{aligned} \bar{p}_{s,\varsigma} &= \int_0^{\bar{\alpha}_\varsigma} \frac{\xi_0(1+z_\varsigma)}{2} dF(\alpha) + \int_{\bar{\alpha}_\varsigma}^1 \frac{\xi(1+z_\varsigma)}{2} dF(\alpha) \\ &= \left( \frac{1+z_\varsigma}{2} \right) (\xi_0 + (\xi - \xi_0)(1 - F(\bar{\alpha}_\varsigma))), \end{aligned} \quad (6)$$

where  $\bar{\alpha}_\zeta$  is parameterized by  $z_\zeta$ . As before, firms choose flexible prices if  $\alpha > \bar{\alpha}_\zeta$ . Thus, the aggregate price  $\bar{p}_{s,\zeta}$  is shifted directly by the cost  $z$  but also depends on demand through the fraction of firms posting flexible prices, determined by  $\bar{\alpha}_\zeta$ .

Because in our model supply shocks do not cause output gaps, the PC will solely capture the relationship between prices and demand pressure. Hence, the appropriate definition is to consider curves parameterized by the supply shock  $z_\zeta$  relating how variations in demand  $\xi_s$  affect prices. Demand shocks move along a PC, while supply shocks shift the PC (change the intercept). When the supply shock is  $z_\zeta$ , we have a curve with slope  $\bar{\kappa}_\zeta$  connecting  $(\bar{x}_{s,\zeta}, \bar{p}_{s,\zeta})$  and  $(0, \bar{p}_{0,\zeta})$ , where  $\bar{x}_{s,\zeta}$  denotes the output gap when demand is  $\xi_s$  and the supply shock is  $z_\zeta$ . Defining  $\bar{\alpha}_\zeta \equiv \frac{1-z_\zeta}{\frac{\xi_H}{\xi_L}(1+z_\zeta)-2z_\zeta}$ , the slopes of the PCs given  $z_\zeta$  are

$$\bar{\kappa}_\zeta = \xi \left( \frac{1 - F(\bar{\alpha}_\zeta)}{\int_0^{\bar{\alpha}_\zeta} \alpha \, dF(\alpha)} \right).$$

The levels of prices are shifted by the cost  $z_\zeta$ , and the slopes in the states may differ because  $\bar{\alpha}$  depends on  $z_\zeta$ .  $\bar{\alpha}$  is decreasing in  $z_\zeta$  and therefore the lowest cutoff occurs when the supply shock takes value  $z_H$  (i.e., more firms choose sticky prices when the supply shock is low). Define  $\delta \equiv \xi_H/\xi_L$  and  $\underline{\delta}_H \equiv \frac{1-z_H+2z_H\alpha_1}{\alpha_1(1+z_H)}$ . If  $\delta < \underline{\delta}_H$ , then on every island  $\alpha < \bar{\alpha}_\zeta$  for every realization of  $z_\zeta$ . This means that the sticky price is consistent with PBE (there are not enough Insiders to induce firms to choose flexible prices). This means that  $\bar{\kappa}_\zeta = 0$ ; the PC is perfectly flat with respect to demand shocks, but supply shocks create meaningful inflation. The following is an immediate consequence.

**COROLLARY 1** (Phillips Curve Under Demand and Supply Shocks). *If  $\delta < \underline{\delta}_H$ , then  $\bar{\kappa}_\zeta = 0$  for all  $z_\zeta$ ; the PC is perfectly flat with respect to demand shocks, but supply shocks create inflation ( $\lambda = 1$ ).*

Corollary 1 is crucial. Our model predicts that strategic price stickiness can lead to a completely flat PC with  $\kappa = 0$  and also that supply shocks can meaningfully feed through to inflation. Notice that for the sticky price  $p_{0,\zeta}$ , the elasticity  $\lambda$  with respect to  $z_\zeta$  is 1. The responsiveness of prices to supply shocks will always exceed

the responsiveness to demand shocks. If residual demand shocks are not very volatile, then the PC will be completely flat, with all firms choosing prices that are sticky with respect to demand but flexible with respect to supply. Even if some firms choose flexible prices (i.e., if  $\delta > \underline{\delta}_H$ ), some firms will choose prices that are sticky with respect to demand (and flexible with respect to supply), but all firms will choose prices that are flexible with respect to supply.

**Log-Linearized PC.** To better understand our results, it is useful to derive a log-linearized approximation of the PC to compare it with the standard NKPC. We add time indices to the equation, consistent with the notation of the infinite-horizon model in the appendix (and suppress notation for states  $s, \varsigma$ ).

**PROPOSITION 3 (Log-Linearized PC).** *If  $\delta < \underline{\delta}_H$ , we can write inflation in terms of the output gap as*

$$\hat{\pi}_t = \kappa \hat{x}_t + \hat{z}_t, \quad (7)$$

where hats denote percentage deviations from steady state, and  $\kappa = \frac{1-z_0}{1+z_0} \bar{\kappa}$  is the PC slope defined in terms of percentage deviations around the steady state.

With a flat PC we have  $\kappa \approx 0$ , and so output gaps do not move inflation, while the supply shock  $\hat{z}$  does. When the PC is flat, inflation is not at all responsive to demand shocks, but inflation remains very responsive to supply shocks in our model. In sum, our model can endogenously produce a perfectly flat PC with inflation that is responsive to structural supply shocks.

Equation (7) is the analog to the standard NKPC, which, dropping inflation expectations (as justified, for instance, in Bilbiie 2018, 2019), is written  $\hat{\pi}_t = \kappa \hat{x}_t + \lambda \hat{z}_t$ , with  $\lambda \approx 0$ . Thus, our model produces a PC in which supply shocks are not modified by an additional coefficient that is nearly zero. In fact, in the NK model, a flat PC implies that the intercept is locked in at the steady state, making it impossible to get inflation out of supply shocks.

### 3.5 Structural Cost-Push Shocks

Our model, with Equation (7), offers a structural theory of cost-push shocks. To see this, it is useful to consider the characterization of a



cost-push shock as one that the central bank cannot fully offset by closing the output gap. In our model, a productivity shock  $\hat{z}_t = -\hat{a}_t$  creates a change in prices but does not itself create an output gap, since prices fully adjust flexibly. Accordingly, if the central bank responds to the shock in order to adjust inflation, it must *create* an output gap, not offset it.

This is not the case in the NK model, in which the central bank can implement *both* zero inflation and zero output gap following a productivity shock. To see this, suppose the model features only preference and productivity shocks. In this case, the NKPC is written in terms of output, not an output gap, as  $\hat{\pi}_t = \kappa\hat{y}_t - \kappa\hat{a}_t$ , where, for ease of comparison, we have made abstraction of forward-looking terms, and where  $\hat{a}_t$  are shocks to log productivity. An inflationary (negative) productivity shock increases marginal costs and inflation. In this setting, the output gap is  $\hat{x}_t = \hat{y}_t - \hat{a}_t$ , which implies the familiar equation  $\hat{\pi}_t = \kappa\hat{x}_t$ . The algebra is trivial, but it shows that productivity shocks cannot play the role of cost-push shocks, because they can be taken care of by closing the output gap, and because they imply the wrong correlation between inflation and the output gap, which remains positive throughout the dynamic effects of the shock. This explains the need to bring in another shock (such as a shock to firms' markups  $\hat{\nu}_t$ ) to fit the data,  $\hat{\pi}_t = \kappa\hat{x}_t + \hat{\nu}_t$ .

When monetary policy follows an interest rate rule (see the next section), our model predicts a negative output gap if the CB raises rates to offset the rise in inflation generated by a negative productivity shock. However, this shock is structural, addressing the early critique by Chari, Kehoe, and McGrattan (2009). Their critique qualifies shocks to markups in the NK framework as “non-structural,” since they do not have an evident counterpart in reality. In our shock-dependent model, plain-vanilla structural shocks, such as shifts in productivity, have cost-push effects. It also explains our focus, in Section 2, on markup shocks within the NK model, and reconciles it with our usage of productivity shocks in the current section.

### 3.6 Discussion: Relation to Other Frictions

In closing the section, the following remarks are in order. First, shock dependence is a unique and novel feature of our model. Conventional models have the common feature of *not* distinguishing

between demand and supply shocks when predicting price adjustment, which, as emphasized earlier, provides a challenge for quantitatively matching aggregate facts. We develop this theme further in Appendix D, where we show qualitatively that, within this model setup, quadratic costs, Calvo-Taylor frictions, and fixed costs are all unable to obtain for cost-push inflation when the PC is entirely flat. Our discussion in the appendix is somewhat simplistic and stylized; a full quantitative analysis in the context of other models is out of the scope of our contribution. However, the intuition we propose is general and applies to all that models that treat demand and supply symmetrically.

Second, besides the analysis in the appendix, a specific discussion of the connection to state-dependent models is warranted. In state-dependent models, larger shocks imply more flexible prices, a point recognized at least since Ball, Mankiw, and Romer (1988). State dependence, and the implied nonlinearities that it offers, constitutes a complementary and promising channel to understand the unprecedented global rise in inflation, where economies around the world have been buffeted by shocks of immense magnitude. However, there, whether the shock is a demand or a supply shock is irrelevant. By way of implication, nonlinearities in price adjustment that depend on the size of the shock also imply sizable adjustment of prices to large demand shocks. A priori, logic suggests that state-dependent models cannot simultaneously predict a flat Phillips curve for large demand shocks (either negative, such as the Great Recession, or positive, such as the housing boom of the early 2000s) and lots of inflation from supply shocks. In our model, the *nature* of the shock, regardless of whether the shock is large or small, is what determines the degree of adjustment. Therefore, prices are completely flexible with respect supply shocks and, at the same time, completely rigid with respect to demand shocks.

#### 4. Quantitative Implications and Monetary Policy

We now provide a calibrated model to determine the quantitative significance of our theoretical results. We have shown that it is theoretically possible to have a flat PC in this setting and for supply shocks to cause inflation. We now show that our proposed mechanism produces an empirically realistic PC given a reasonable

calibration. We then use our calibrated model to consider the aggregate consequences of supply shocks when monetary policy responds to supply shocks.

#### 4.1 Setup and Calibration

We modify the setup slightly in order to let the data discipline the degree of heterogeneity. First, instead of having a distribution of Insiders across islands, we let firms have a distribution of marginal costs. In this way, we can let empirical estimates discipline the distribution of productivity. Second, we explicitly model the behavior of the central bank using a Taylor rule that determines interest rates in equilibrium. Finally, we calibrate the fraction of Insiders to match the estimated slope of the PC, given particular Taylor coefficients disciplined by the data.

**Firm Heterogeneity.** Let the setup be modified as follows. The fraction of Insiders  $\alpha$  is assumed to be constant across islands, but now firms differ in their marginal costs  $z \leq 1$ . Let the idiosyncratic component of marginal costs be distributed according to  $G$ , where  $G$  is a distribution with the usual properties. Because  $\alpha$  is constant across islands, one can show that there is a cutoff for sticky or flexible prices now depends on the marginal cost (see Lemma 4 in Appendix B).

**Monetary Policy.** We suppose the CB responds to the aggregate state  $s$  by setting the nominal interest rate  $i_s$  according to a standard Taylor rule, which we write as

$$i_t^{Taylor} = i_0 + \phi_\pi \widehat{\pi}_t + \phi_x \widehat{x}_t, \quad (8)$$

where  $i_0$  is a base interest rate;  $\phi_\pi$  and  $\phi_x$  are the Taylor coefficients. In equilibrium this means the CB will endogenously set  $i_L \leq i_H$  in response to the endogenous levels of inflation and the output gap. In the model, the effects of monetary policy are akin to the effect of demand shocks, leading endogenous to imperfect price adjustment to policy.<sup>14</sup>

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<sup>14</sup>We suppose that Outsiders do not know the stance of monetary policy but do know the equilibrium distribution of possible interest rates. In this way, consistent with the model in Section 3, Outsiders do not know  $\xi$  even as the CB responds to the supply shock.

In practice, monetary policy rules typically respond to output gaps and to inflation, rather than to a directly observable shock. Therefore, because policymakers do not observe shocks directly, the policy rule responds indirectly through observable macrovariables. The Taylor coefficients  $\phi_\pi$  and  $\phi_x$  will endogenously determine how much the CB changes  $i_t$  in response to the shock.

Solving for equilibrium requires solving a fixed-point problem. Note that the interest rate  $i_t$  determines  $\xi$ , which affects average prices and output—which are themselves the inputs in the Taylor rule. All else being equal, when the Taylor coefficients are large, the CB will respond aggressively to variations in output and prices (offsetting the demand shock), which will endogenously lead to smaller fluctuations in output and demand. In this way, the slope of the PC is determined by the Taylor rule (see L’Huillier, Phelan, and Zame 2022).

**Calibration.** We let the data discipline the degree of heterogeneity in the model, thus calibrating the slope of the PC in equilibrium. We target average markups to be 12.5 percent, as is standard in the literature. With an average price of  $p = \frac{\xi_0(1+z)}{2}$ , we set  $p/z = 1.125$  and  $\xi_0 = 1$ , implying an average marginal cost of 0.8. We calibrate the idiosyncratic distribution of productivities (inverse of marginal costs) as log-normal with standard deviation of 5 percent. Bloom et al. (2018) find that the unconditional standard deviation of micro-productivity shocks is 5.1 percent. The mean of the distribution of productivities is set so that the average marginal cost equals 0.8. The entire distribution of marginal costs shifts with the aggregate supply shock  $\varsigma$  by 1 percent (up or down). The household time preference (natural rate) is set to  $r_0 = 4\%$ , and the discount factor shock (demand shock) is 1 percent. Therefore,  $\theta_L = \frac{1.01}{1+r_0}$  and  $\theta_H = \frac{0.99}{1+r_0}$ .

We choose  $\alpha$  to target the slope of the PC in equilibrium for given Taylor coefficients. We use estimates from Del Negro et al. (2020), who use 1990 as the break in the sample. Their estimates for the relevant Taylor coefficients post-1990 are  $\phi_\pi = 1.5$  and  $\phi_x = 0.22$ . The posterior mean, median, and mode for  $\kappa$  post-1990 are 0.00151, 0.00140, and 0.00196. These estimates are similar to what is found in Hazell et al. (2022). With  $\alpha = 0.88$ , equilibrium features an equilibrium PC slope of  $\kappa = 0.0017$ . In other words, the calibrated model can match the slope of the PC given the estimated Taylor rule parameters.

## 4.2 Results

A calibrated version of our model can produce a flat PC consistent with empirical estimates. Equilibrium features endogenous monetary policy responses and firms with heterogeneous productivities disciplined by empirical estimates. We consider the aggregate dynamics of a 1 percent structural demand shock and a 1 percent structural supply shock (an increase in marginal costs of 1 percent), each decaying at a rate of 0.9. We shut down learning dynamics so that  $\alpha = 0.88$  is constant across time. (The simulation is obtained by simply repeating the short-run equilibrium presented above.)

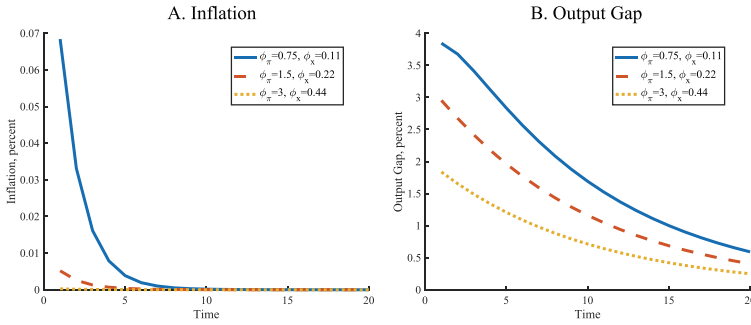
In this model, demand shocks produce virtually no change in average prices. In contrast, a 1 percent aggregate productivity shock, which would change marginal costs by 1 percent, changes aggregate prices by 0.45 percent on impact. Thus, empirically plausible supply shocks can produce meaningful inflation even while demand shocks produce a very flat PC.

We first consider a decaying demand shock. Figure 2 plots inflation and the output gap given a 1 percent demand shock. We also consider variation in monetary policy, by considering more and less hawkish Taylor rules. A dovish monetary policy (MP) response follows a Taylor rule with coefficients multiplied by 1/2, and a hawkish MP response follows a Taylor rule with coefficients multiplied by 2. The demand shock generates a positive output gap and negligible inflation (note the scale on the y-axis). In response to the demand shock, the CB raises rates by almost 70 basis points (bps) on impact with the baseline Taylor rule, decaying to about 10 bps (not shown).

Figure 3 instead considers the aggregate consequences of a structural supply shock. In this case, we vary the aggressiveness of the central bank in responding to inflation by varying  $\phi_\pi$  alone while fixing  $\phi_x$  at the baseline. In the hawkish case, the central bank has twice the response to inflation without changing its weight on the output gap. In the dovish case, we set  $\phi_\pi = 0$  and in equilibrium there is no monetary policy response to a supply shock (interest rates are constant).

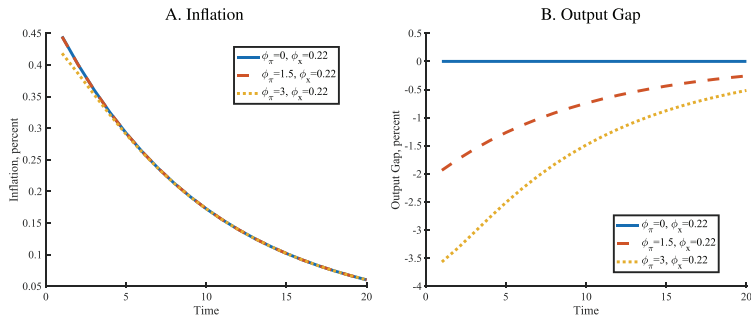
The theoretical result of this benchmark model is that a supply shock leads to a flexible change in prices with respect to the cost shock, but prices can remain sticky with respect to changes in demand, which in this case would be variations in monetary policy. Accordingly, a 1 percent structural supply shock leads to

**Figure 2. Aggregate Consequences of a Demand Shock for Inflation and Output, Varying the Monetary Policy Rule**



**Note:** Red: baseline Taylor rule; blue: dovish MP with Taylor coefficients multiplied by 1/2; yellow: hawkish MP with Taylor coefficients multiplied by 2.

**Figure 3. Aggregate Consequences of a Supply Shock for Inflation and Output, Varying the Hawkishness of the Monetary Policy Rule**



**Note:** Red: baseline Taylor rule; blue: dovish MP,  $\phi_\pi = 0$ ; yellow: hawkish MP,  $\phi_\pi = 3$ .

0.45 percent inflation on impact (orders of magnitude larger than the effects from a demand shock) and meaningful negative output gaps in response to the increase in interest rates. In this case, more aggressive monetary policy leads to larger output gaps. Crucially, the inflation outcomes in all three scenarios are virtually identical: the central bank response has virtually no effect on inflation. Importantly, an aggressive monetary policy is not enough to bring down inflation.

When the central bank does not respond at all to the supply shock, there is no output gap (flexible price equilibrium). Moreover, even a very hawkish response that puts twice the baseline weight on inflation leads to almost no change in inflation. An extremely hawkish response, tripling of the Taylor coefficient to  $\phi_\pi = 4.5$ , would raise rates in equilibrium by 60 bps in response to a 1 percent supply shock and would still yield 0.32 percent inflation on impact while creating a negative output gap of almost 4 percent. Our results suggest that a central bank attempting to bring down inflation in response to a supply shock faces a daunting task. Because the PC is very flat, a very aggressive response in interest rates is likely to have a large negative effect on output without a significant effect on inflation.

In our simple benchmark model, our theoretical results suggest that the increase in prices in response to a supply shock would be efficient; the central bank should not respond by raising rates. Our analysis emphasizes the positive implications of alternative interest rate rules, and provides insights about policy considerations, but fully characterizing the optimal policy solution with shock-dependent price stickiness is out of the scope of the paper. Also, in reality, there are likely to be other frictions and rigidities in the economy so that inflation may be costly. We have left out, for example, the possibility of embedded inflation expectations responding in adverse ways. Our analysis nonetheless highlights the policy challenges in responding to inflation in the event that supply shocks lead to flexible price inflation. To the extent that prices are less rigid in response to supply shocks than to demand shocks, the welfare losses due to nominal rigidities would necessarily be lower. The next section provides empirical evidence that, indeed, aggregate prices are more flexible with response to cost shocks, suggesting that the welfare considerations of supply shocks are lower than those of demand shocks.

## 5. Empirical Evidence

In this section, we provide U.S. time-series evidence supporting the view that cost-push shocks lead to stronger short-run inflation responses than demand shocks. Specifically, we identify both of these shocks using a state-of-the-art procedure. For a similar effect on U.S. industrial production (IP), we show that whereas demand shocks lead to a relatively small inflation response in the short run,

cost-push shocks deliver a response that is about 2.5 times larger over two years and more than 5 times larger over one year.

Our empirical approach is fairly off-the-shelf. The simple time-series exercise we present essentially collects and combines findings from recent studies. Both types of shocks are identified using external instruments. In order to identify the effect of demand shocks on inflation and output, we consider well-identified monetary shocks based on the instrument proposed by Gertler and Karadi (2015). We follow their procedure closely by running a vector autoregression (VAR) on log IP, the log CPI, the one-year government bond rate (as the policy indicator), and a credit spread, and by using the three-month-ahead funds rate future surprise to identify monetary policy shocks.

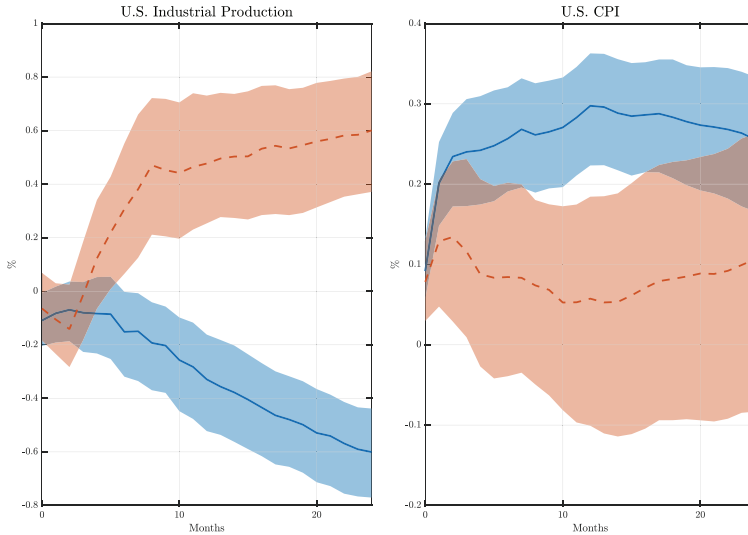
In order to identify the effect of cost-push shocks on inflation and output, we consider well-identified oil news shocks based on Känzig (2021). Here, we also follow his procedure closely by running a VAR on the real price of oil, world oil production, world oil inventories, world IP, U.S. industrial production, and the log CPI, and by using his series of high-frequency surprises around OPEC announcements to identify oil shocks.

For both exercises, the data are monthly and the sample spans from April 1983 through December 2017. Both VARs have 12 lags. Having identified the shocks, we compute the impulse response functions (IRFs) of IP and inflation. As expected, following a monetary shock, IP and inflation comove, but they do not following a cost-push shock. For both types of shocks, we consider a shock that raises inflation (i.e., an expansionary monetary shock and a contractionary cost-push shock). We set the size of an oil news shock to one standard deviation and compute the responses of IP and CPI. We then scale the size of a monetary shock as follows: we compute the IP response after the cost-push shock at a horizon of 24 months, and then we resize the monetary shock to deliver the same IP response at the same horizon (in absolute value).

Figure 4 presents the results. It plots the IRFs at the point estimate, and the corresponding 68 percent error bands. Looking at the monetary shock (the dashed red line), we see that IP rises gradually and reaches a 0.60 percent increase in 24 months. The CPI raises by roughly 0.10 percent on impact of the shock and then stays roughly constant over the horizon considered. For the cost-push shock (the solid blue line), we estimate a gradual decline in IP, with a fairly



**Figure 4. Estimated Responses of U.S. Industrial Production and the Consumer Price Index to a Monetary Shock (dashed red line) and to a Cost-Push Shock (solid blue line)**



**Note:** The cost-push shock is resized to deliver an IP response of the same size at 24 months.

rapid rise in the CPI that peaks at 0.30 percent at 12 months. The inflation response drops slightly thereafter, settling at 0.25 percent after 24 months.

Overall, for a similar effect on IP, we note that the response of inflation in the case of the cost-push shock is roughly 2.5 times larger than in the case of the monetary shock over 24 months and more than 5 times larger over 12 months. Moreover, the response in the case of the cost-push shock is statistically different from zero at all horizons, whereas the response to the monetary shock is actually not different from zero for the majority of the response.

## 6. Conclusion

Inflation data point toward a very flat Phillips curve, and also to meaningful inflation caused by supply disturbances. These two

features suggest that a model with shock-dependent friction is a promising candidate for understanding inflation dynamics.

Motivated by this idea, we provide a microfoundation of price stickiness based on strategic behavior of informed firms that can simultaneously produce both a very flat PC and also inflation in response to supply shocks. When demand shocks hit, firms strategically choose sticky prices that do not fluctuate. In contrast, firms have no strategic incentive to choose prices that do not fluctuate in response to marginal costs, and therefore prices are flexible with respect to changes in supply.

Our model does not need to resort to implausibly large structural shocks to firms' pricing decisions. Prices can be completely flexible with respect to supply shocks and yet remain rigid with respect to demand shocks, including changes in monetary policy. Interestingly, this result might be seen as providing justification for the standard practice of normalizing cost-push shocks in the NKPC and not multiplying by the proper coefficient  $\lambda$  (or "appending a cost-push shock"), because doing so implicitly allows for shock dependence with greater responsiveness of inflation to cost-push shocks. A calibrated version of our model shows that a 1 percent structural cost shock could increase inflation on impact by 0.45 percent and suggests that central banks might find it challenging to bring down inflation with interest rate increases.

More research is required on the broader consequences of shock-dependent rigidities. Our baseline model does not incorporate any other frictions aside from nominal rigidities at the level of firms' pricing decisions. Future work ought to consider the role of wage rigidities, which are unlikely to share the same microfoundation as we have proposed at the level of product prices.

## Appendix A. Main Proofs

*Proof of Lemma 1.* ONLY IF: To find the cutoff  $\bar{\alpha}$ , we need to confirm that in the low state the firm would rather charge the low flexible price than the high flexible price (which would fool the uninformed agents). If the flexible price  $\{p_s\}$  is consistent with some PBE, then if the true state is  $L$  the firm will not prefer to deviate and offer the price  $p_H$  rather than the price  $p_L$ . Note that if the true state is  $L$  and the firm offers  $p_H$ , Insiders will know that

the true state is  $L$  but Outsiders will believe the true state is  $H$ . Hence the firm will not want to offer  $p_H = \xi_H(1+z)/2$  rather than  $p_L = \xi_L(1+z)/2$  if and only if

$$\begin{aligned} & \left( \frac{\xi_L(1+z)}{2} - z\xi_L \right) \left[ 1 - \frac{\xi_L(1+z)}{2} \frac{1}{\xi_L} \right] \\ & \geq \left( \frac{\xi_H(1+z)}{2} - z\xi_L \right) \left\{ \alpha \left[ 1 - \frac{\xi_H(1+z)}{2} \frac{1}{\xi_L} \right] \right. \\ & \quad \left. + (1-\alpha) \left[ 1 - \frac{\xi_H(1+z)}{2} \frac{1}{\xi_H} \right] \right\}. \end{aligned}$$

Simplifying,

$$\begin{aligned} \xi_L \frac{(1-z)}{2} \left( \frac{1-z}{2} \right) & \geq \left( \frac{\xi_H(1+z) - 2\xi_L z}{2} \right) \left( \alpha \left( \frac{2 - (1+z)\xi_H/\xi_L}{2} \right) \right. \\ & \quad \left. + (1-\alpha) \left( \frac{1-z}{2} \right) \right) \\ \xi_L(1-z)(1-z) & \geq (\xi_H(1+z) - 2\xi_L z) (\alpha(2 - (1+z)\xi_H/\xi_L) \\ & \quad + (1-\alpha)(1-z)). \end{aligned}$$

Letting  $\delta \equiv \xi_H/\xi_L$  and dividing both sides by  $\xi_L$ ,

$$\begin{aligned} (1-z)(1-z) & \geq (\delta(1+z) - 2z) (\alpha(2 - (1+z)\delta) + (1-\alpha)(1-z)) \\ (1-z)(1-z) & \geq (\delta(1+z) - 2z) ((1-z) + \alpha(1+z)(1-\delta)). \end{aligned}$$

Note that  $\delta(1+z) - 2z > 1-z$  and  $\delta > 1$  so that  $1-\delta < 0$ . Then, rearranging, we have

$$\begin{aligned} & \alpha(1+z)(\delta-1)(\delta(1+z)-2z) \\ & \geq (\delta(1+z)-2z)(1-z) - (1-z)(1-z)\alpha \geq \frac{1-z}{\delta+\delta k-2z} \equiv \bar{\alpha}, \end{aligned}$$

which is the desired result. Note that if  $z=0$ , then we get  $\bar{\alpha} = 1/\delta$ .

IF: Given that  $\alpha \geq \bar{\alpha}$ , we must construct a PBE in which prices along the equilibrium path are  $p_L, p_H$ . Hence we must show that when the true state is  $s$ , the firm will not wish to deviate to a price  $p \neq p_s$ . PBE implies that when the Outsiders see the price  $p_s$ , they

believe the true state is  $s$ , as in (a) and (c) below. However, we are free to assign arbitrary beliefs to Outsiders if they see a price  $p$  different from both  $p_L$  and  $p_H$ , as in (b) and (d); in that event we assign to Outsiders the belief that the true state is  $L$ . We must rule out four kinds of potentially profitable deviations:

- (a) The true state is  $L$  and the firm offers  $p_H$ .
- (b) The true state is  $L$  and the firm offers  $p \neq p_L, p_H$ .
- (c) The true state is  $H$  and the firm offers  $p = p_H$ .
- (d) The true state is  $H$  and the firm offers  $p \neq p_L, p_H$ .

When Outsiders see a price  $p \neq p_L, p_H$ , they believe the state is  $L$ , and PBE guarantees that when Outsiders see the price  $p_L$ , they believe the state is  $L$ , so we can subsume (c), (d) into the following:

- (e) The true state is  $L$  and the firm offers  $p \neq p_H$ .

We now verify (a), (b), and (e) in turn.

- (a) This follows immediately by following the steps in the ONLY IF case above, but in reverse order, noting that each inequality is *equivalent* to the one above.
- (b) We have posited that when Outsiders see a price  $p \neq p_L, p_H$ , they believe the state is  $L$ . Insiders know the true state, so they also believe the state is  $L$ . Hence aggregate demand if the firm offers  $p$  will be  $1 - p \frac{1}{\xi_L}$  and firm profit will be  $(p - z\xi_L)[1 - p \frac{1}{\xi_L}]$ . By definition, this quantity is maximized when  $p = 1/2 \frac{(1+z)}{\xi_L}$ , and the maximum profit will be  $1/4 \frac{(1-z)^2}{\xi_L}$ . However, this is the profit when the firm offers  $p_L$ , so this cannot be a profitable deviation for any such  $p$ .
- (e) We must show that when the true state is  $H$ , the firm's profit if it offers  $p_H$  is at least as great as when it offers  $p \neq p_H$ ; i.e., we must show

$$\begin{aligned}
\frac{\xi_H(1-z)^2}{4} &\geq (p - z\xi_H) \left( \alpha \left[ 1 - p \frac{1}{\xi_H} \right] + (1-\alpha) \left[ 1 - p \frac{1}{\xi_L} \right] \right) \\
&= \alpha(p - z\xi_H) \left[ 1 - p \frac{1}{\xi_H} \right] + (1-\alpha)(p - z\xi_H) \left[ 1 - p \frac{1}{\xi_L} \right].
\end{aligned} \tag{A.1}$$

By definition,  $(p - z\xi_H)[1 - p \frac{1}{\xi_H}]$  would be maximized by setting  $p = p_H$  and  $(p - z\xi_H)[1 - p \frac{1}{\xi_L}]$  would be maximized by setting  $p = p_L$ , so we must certainly have

$$\alpha(p - z\xi_H) \left[ 1 - p \frac{1}{\xi_H} \right] \leq \alpha \left( \frac{\xi_H(1-z)^2}{4} \right) \tag{A.2}$$

$$(1-\alpha)(p - z\xi_H) \left[ 1 - p \frac{1}{\xi_L} \right] \leq (1-\alpha) \left( \frac{\xi_L(1-z)^2}{4} \right). \tag{A.3}$$

The result follows by adding the inequalities (A.2) and (A.3) together with  $\xi_H > \xi_L$ , so we have verified (e). Having verified (a), (b), and (e), the proof is complete.  $\square$

*Proof of Lemma 2.* Assume the sticky price  $p_0 = \xi_0(1+z)/2$  is consistent with some PBE. Suppose that, in that PBE, the true state is  $L$  and the firm offers a price  $p \neq p_0$ . Because the Insiders know the true state, they will demand the quantity  $1 - p \frac{1}{\xi_L}$ . PBE requires that the Outsiders form some belief about the true state and demand a quantity that is optimal with respect to that belief about the true state; hence the Outsiders will demand  $1 - p \mathbb{E}_o \left[ \frac{1}{\xi} \right]$ , where  $\mathbb{E}_o \left[ \frac{1}{\xi} \right]$  is their expectation of the shock. The profit of the firm will be

$$d_L(p) = (p - z\xi_L) \left( \alpha \left[ 1 - p \frac{1}{\xi_L} \right] + (1-\alpha) \left[ 1 - p \mathbb{E}_o \left[ \frac{1}{\xi} \right] \right] \right).$$

For every  $p \neq p_0$ , this expression will be minimized if the Outsiders assign probability 1 to the state  $L$ , in which case their expectation of the shock will be  $E_o(\frac{1}{\xi_s}) = \frac{1}{\xi_L}$ . Hence if the firm offers  $p \neq p_0$ , we must have

$$d_L(p) \geq (p - z\xi_L) \left[ 1 - p \frac{1}{\xi_L} \right].$$

In PBE the firm has no profitable deviation, so it must be that  $d_L(p_0) \geq d_L(p)$  for every  $p$ ; in particular, this inequality must hold when  $p = p_L$ . We conclude that

$$\left( \frac{\xi_0(1+z)}{2} - z\xi_L \right) \left( \alpha \left[ 1 - \frac{\xi_0(1+z)}{2} \frac{1}{\xi_L} \right] + (1-\alpha) \left[ 1 - \frac{\xi_0(1+z)}{2} \mathbb{E}_o \left[ \frac{1}{\xi} \right] \right] \right) \geq \frac{\xi_L(1-z)^2}{4}.$$

Because  $\xi_0$  is the harmonic mean of  $\xi_L, \xi_H$ ,  $\mathbb{E}_o \left[ \frac{1}{\xi} \right] = 1/\xi_0$ , substituting and simplifying yields

$$\begin{aligned} & (\xi_0(1+z) - 2z\xi_L) \left( \alpha \left[ 2 - \frac{\xi_0(1+z)}{\xi_L} \right] + (1-\alpha)(1-z) \right) \\ & \geq \xi_L(1-z)^2. \end{aligned}$$

The left-hand side (LHS) is decreasing in  $\alpha$ ; we must set  $\alpha$  sufficiently low. Note that if  $\alpha = 0$ , then the LHS equals  $(\xi_0(1+z) - 2z\xi_L)(1-z)$  and  $\xi_0(1+z) - 2z\xi_L = \xi_0 + (\xi_0 - \xi_L)z - z\xi_L > \xi_L(1-z)$  since  $\xi_0 > \xi_L$ . Thus, there exists a threshold  $\bar{\alpha}_0 > 0$  such that this inequality holds if  $\alpha \leq \bar{\alpha}_0$ . Let  $\delta_{0L} \equiv \frac{\xi_0}{\xi_L}$ . Then

$$\begin{aligned} & (\delta_{0L}(1+z) - 2z)(\alpha[2 - \delta_{0L}(1+z)] + (1-\alpha)(1-z)) \geq (1-z)^2 \\ & (\delta_{0L}(1+z) - 2z)(1-z + \alpha[2 - \delta_{0L}(1+z) - (1-z)]) \geq (1-z)^2 \\ & (1-z) - \alpha(\delta_{0L} - 1)(1+z) \geq \frac{(1-z)^2}{\delta_{0L}(1+z) - 2z}. \end{aligned}$$

Recall that  $\delta_{0L} > 1$  since  $\xi_L < \xi_0$ , and therefore we have

$$\begin{aligned} & (1-z) - \frac{(1-z)^2}{\delta_{0L}(1+z) - 2z} \geq \alpha(\delta_{0L} - 1)(1+z) \\ & \frac{(1-z)(\delta_{0L} - 1)(1+z)}{\delta_{0L}(1+z) - 2z} \geq \alpha(\delta_{0L} - 1)(1+z). \end{aligned}$$

And therefore we can simplify to  $\alpha \leq \frac{1-z}{\delta_{0L}(1+z)-2z} \equiv \bar{\alpha}_0$ . Recall that

$$\bar{\alpha} \equiv \frac{1-z}{\delta(1+z) - 2z} < \frac{1-z}{\delta_{0L}(1+z) - 2z}$$

since  $\delta \equiv \xi_H/\xi_L > \delta_{0L} \equiv \xi_0/\xi_L$ . Thus, if  $\alpha < \bar{\alpha}$ , it follows that  $\alpha < \bar{\alpha}_0$  and therefore  $p_0$  is a PBE.

To construct a PBE in which  $p_0$  is offered in both states, we have to prescribe the behavior of Outsiders when a price  $p \neq p_0$  is offered. As the argument above suggests, we posit that when a price  $p \neq p_0$  is offered, Outsiders believe the true state is  $L$  and hence demand  $1 - p\frac{1}{\xi_L}$ . Insiders know the true state  $s$  and demand  $1 - p\frac{1}{\xi_s}$ , so the profit of the firm is

$$d_s(p) = (p - z\xi_s) \left( \alpha \left[ 1 - p\frac{1}{\xi_s} \right] + (1 - \alpha) \left[ 1 - p\frac{1}{\xi_L} \right] \right). \quad (\text{A.4})$$

If the firm offers the putative equilibrium price  $p_0$ , the Outsiders' expectation of the future price will be  $1/\xi_0$ , so the profit of the firm will be

$$\begin{aligned} d_s(p_0) &= \left( \frac{\xi_0(1+z)}{2} - z\xi_s \right) \left( \alpha \left[ 1 - \frac{\xi_0(1+z)}{2} \frac{1}{\xi_s} \right] + \frac{(1-\alpha)(1-z)}{2} \right). \end{aligned}$$

The equilibrium condition is that

$$d_s(p_0) \geq d_s(p) \quad (\text{A.5})$$

when  $s = L$  and when  $s = H$ , under the assumption that  $\alpha \leq \bar{\alpha}$ . That the inequality (A.5) is satisfied when the true state  $s = L$  follows from the exercise we just did. To see that (A.5) is satisfied when the true state  $s = H$  is more complicated. First note that simplifying the right-hand side (RHS) of (A.4) yields

$$d_H(p) = (p - z\xi_H) \left( 1 - p \left[ \alpha \frac{1}{\xi_H} + (1 - \alpha) \frac{1}{\xi_L} \right] \right).$$

Define  $\xi_\alpha \equiv \left( \alpha \frac{1}{\xi_H} + (1 - \alpha) \frac{1}{\xi_L} \right)^{-1}$  as the  $\alpha$ -weighted harmonic mean of  $\xi_s$ . Since  $\xi_\alpha < \xi_H$ ,

$$d_H(p) < (p - z\xi_\alpha) \left( 1 - p \left[ \alpha \frac{1}{\xi_H} + (1 - \alpha) \frac{1}{\xi_L} \right] \right)$$

and the RHS is maximized by setting  $p = \frac{\xi_\alpha(1+z)}{2}$  and equals  $\frac{\xi_\alpha(1-z)^2}{4}$ . Thus, it suffices to show that for  $\alpha \leq \bar{\alpha}_0$ ,

$$(p_0 - z\xi_H) \left( 1 - p_0 \left[ \alpha \frac{1}{\xi_H} + (1 - \alpha) \frac{1}{\xi_0} \right] \right) \geq \frac{\xi_\alpha(1-z)^2}{4}.$$

Note first that this is satisfied for  $\alpha = 0$  but not for  $\alpha = 1$ ; in the first case there are no Informed agents, so setting  $p = p_0$  is strictly dominant; in the second case there are only Informed agents, so the flexible price is optimal. Rearranging, we have

$$(p_0 - z\xi_H) \left( 1 - p_0 \frac{1}{\xi_0} + p_0 \alpha \left( \frac{1}{\xi_0} - \frac{1}{\xi_H} \right) \right) \geq \frac{(1-z)^2}{4 \left( \frac{1}{\xi_L} - \alpha \left( \frac{1}{\xi_L} - \frac{1}{\xi_H} \right) \right)}.$$

Note that the LHS is increasing linearly in  $\alpha$  since  $\frac{1}{\xi_0} - \frac{1}{\xi_H} > 0$ . The RHS is increasing with  $\alpha$ . Multiplying, we have

$$\begin{aligned} & \left( \frac{1}{\xi_L} - \alpha \left( \frac{1}{\xi_L} - \frac{1}{\xi_H} \right) \right) (p_0 - z\xi_H) \left( 1 - p_0 \frac{1}{\xi_0} + p_0 \alpha \left( \frac{1}{\xi_0} - \frac{1}{\xi_H} \right) \right) \\ & \geq \frac{(1-z)^2}{4}, \end{aligned}$$

which is a quadratic equation in  $\alpha$  with a negative coefficient on  $\alpha^2$ . Thus, if this holds at  $\bar{\alpha}_0$ , it holds for all  $\alpha \leq \bar{\alpha}_0$ . L'Huillier, Phelan, and Zame (2022) verify that this condition holds for  $z = 0$ . By continuity it holds for  $z$  sufficiently small.  $\square$

*Proof of Lemma 3.* First, to derive  $\bar{\kappa}$ , from Equations (3) and (4), we can derive more convenient expressions for the average price and demand difference:

$$\bar{p}_s - \bar{p}_0 = \frac{1}{2} (\xi - \xi_0) (1+z) (1 - F(\bar{\alpha})), \quad (\text{A.6})$$

$$\bar{x}_s = \frac{(1+z)}{2} \left( \frac{\xi - \xi_0}{\xi} \right) \int_0^{\bar{\alpha}} \alpha \, dF(\alpha). \quad (\text{A.7})$$

The price difference is the difference in the flexible prices for the measure of firms using flexible prices. The output difference is the difference in demand from Insiders on islands with sticky prices.



Define  $\delta \equiv \xi_H/\xi_L$ . Note that  $\delta \geq 1$  and decreases as  $\xi_H \rightarrow \xi_L$ . Define  $\underline{\delta} \equiv \frac{1-z+2z\alpha_1}{\alpha_1(1+z)}$ . We show that  $\bar{\kappa} = 0$  whenever  $\delta < \underline{\delta}$ . First,  $\bar{\alpha}$  is decreasing in  $\delta$  and equals 1 when  $\delta = 1$ ; the fraction of islands posting sticky prices increases when  $\delta$  is lower, converging to 1. Thus, the numerator decreases, the denominator increases, and  $\delta$  decreases to 1. Therefore,  $\bar{\kappa}$  is increasing in  $\delta$ , as  $\delta \rightarrow 1$   $\bar{\alpha} \rightarrow 1$  and all islands post sticky prices. If  $\delta < \underline{\delta}$ , then  $\bar{\alpha} > \alpha_1$ , which means that  $F(\bar{\alpha}) = 1$ , all islands post sticky prices, and  $\bar{\kappa} = 0$ . Second,  $\xi \rightarrow \xi_0$  as  $\delta \rightarrow 1$ .  $\square$

*Proof of Proposition 1.* The proof is immediate. Note that conditional on the price  $p$ , Insiders and Outsiders have the same demand,  $x = 1 - p\xi_0$ . Thus, profit maximization means choosing  $p$  to maximize  $(1 - p\xi_0)(p - z_\zeta)$ , which yields the desired result.  $\square$

## Appendix B. Additional Proofs

### B.1 Proofs for Section 3.4, Strategic Model with Supply and Demand Shocks

*Proof of Proposition 2.* The proof follows quickly from earlier results. First, the firm can choose prices that communicate information about  $\xi_s$ , thus achieving full information. Let  $p_{s,\zeta}$  denote the price when demand is  $\xi_s$  and supply is  $z_\zeta$ . The full-information prices are given by

$$\begin{aligned} p_{H,H} &= \frac{\xi_H(1+z_H)}{2}, p_{L,H} = \frac{\xi_L(1+z_H)}{2}, \\ p_{H,L} &= \frac{\xi_H(1+z_L)}{2}, p_{L,L} = \frac{\xi_L(1+z_L)}{2}. \end{aligned}$$

Second, the firm can choose prices that do not communicate information about  $\xi_s$ . Since the demand shock is orthogonal to the shock to  $z_\zeta$ , it is easy to show that the following prices maximize profits (as in the previous proof) without communicating information regarding  $\xi_s$ :

$$p_{0,H} = \frac{\xi_0(1+z_H)}{2}, \quad p_{0,L} = \frac{\xi_0(1+z_L)}{2}.$$

Except by coincidence, these six prices are all distinct. Hence, in the high cost state ( $z_H$ ), the firm can choose a price that is sticky with respect to  $\xi_s$  by offering  $p_{0,H} = \frac{\xi_0(1+z_H)}{2}$ ; the firm can choose a price that is flexible with respect to  $\xi_s$  by offering  $p_{s,H} = \frac{\xi_s(1+z_H)}{2}$ . The cutoff for choosing the sticky or flexible price is given by the threshold in Lemma 1 for a given  $z_\zeta$ . Recall that  $\bar{\alpha}$  is decreasing in  $z_\zeta$ , so  $\bar{\alpha}_H < \bar{\alpha}_L$  and therefore  $\alpha < \bar{\alpha}$  for both realizations of the supply shock.

In this way, the firm can choose a price that is flexible with respect to both shocks by offering  $p_{s,\zeta} = \frac{\xi_s(1+z_\zeta)}{2}$  or a price that is flexible with respect to the cost shock only by offering  $p_{0,\zeta} = \frac{\xi_0(1+z_\zeta)}{2}$ , which is sticky with respect to demand. The remaining results follow immediately from Lemma 3.

Conditional on the price  $p$ , agents have the demand,  $x = 1 - p\mathbb{E}\left[\frac{1}{\xi_s}\right]$ . Hence, any incentive for firms to convey or hide information via  $p$  can only operate through the expectation on  $\xi_s$ .

In the proposed equilibrium, Outsiders see a price  $p_{0,\zeta}$  and conclude it conveys information about the marginal cost alone ( $p_{0,\zeta} = \frac{1+z_\zeta}{2}\xi_0$ ); they do not learn the demand shock or update their demands. Given these beliefs, on islands with a small number of Insiders, the firms' problem is equivalent to determining the profit-maximizing price as if the demand shock is  $\xi_0$ , which provides the price above. By our assumption that  $\delta < \delta_H$ , no island has a sufficiently high number of Insiders for the firm to want to set a price that responds to the demand shock. On each island, the fraction of Outsiders is large enough so that firms choose the price  $p_{0,\zeta} = \frac{1+z_\zeta}{2}\xi_0$ , taking as given that Outsiders will set their demand with  $x_{0,\zeta} = 1 - p_{0,\zeta}\mathbb{E}\left[\frac{1}{\xi_0}\right]$ . Thus, no firm on any island adjusts prices in response to demand, but every firm on every island adjusts prices in response to costs.  $\square$

*Proof of Proposition 3.* Since prices are generally proportional to  $1+z$ , it is useful to define a supply shock as the value  $1+z$ . Let  $\bar{p}_0 = \frac{1+z_0}{2}\xi_0$  denote the steady-state price level. We suppose the economy starts at steady state, and therefore this is the prior price level. Inflation is  $\hat{\pi} \equiv \frac{\bar{p}-\bar{p}_0}{\bar{p}_0}$ . It is useful to define the shocks  $\hat{\xi} \equiv \frac{\xi-\xi_0}{\xi_0}$  and  $\hat{z} \equiv \frac{\Delta z}{1+z_0}$ , and the percentage output gap  $\hat{x} = \frac{\bar{x}-\bar{x}_0}{\bar{x}_0}$ .

Rearranging  $\bar{\kappa} \equiv \frac{\bar{p}-p_0}{\bar{x}-\bar{x}_0}$ , we have  $\bar{p} - p_0 = \bar{\kappa}(\bar{x} - \bar{x}_0)$ . Note that  $z = z_0 + \Delta z$  and therefore

$$p_0 \equiv \frac{1+z}{2}\xi_0 = \frac{1+z_0+\Delta z}{2}\xi_0 = \bar{p}_0 + \frac{\Delta z}{2}\xi_0.$$

Alternatively,  $\frac{p_0}{\bar{p}_0} = 1 + \hat{z}$ . Therefore,  $\frac{\bar{p}-p_0}{\bar{p}_0} = \frac{\bar{p}-p_0}{\frac{1+z_0}{2}\xi_0} + \hat{z}$ . Using  $\bar{p} - p_0 = \bar{\kappa}(\bar{x} - \bar{x}_0)$ , we have

$$\hat{\pi} = \frac{\bar{\kappa}}{\frac{1+z_0}{2}\xi_0}(\bar{x} - \bar{x}_0) + \hat{z} = \frac{2\bar{\kappa}}{(1+z_0)\xi_0}(\bar{x} - \bar{x}_0) + \hat{z}.$$

To write this in terms of a percentage output gap  $\hat{x}$ ,

$$\begin{aligned} \hat{\pi} &= \frac{2\bar{\kappa}}{(1+z_0)\xi_0}\bar{x}_0\left(\frac{\bar{x} - \bar{x}_0}{\bar{x}_0}\right) + \hat{z}, \\ &= \frac{2\bar{\kappa}}{(1+z_0)\xi_0}\left(\frac{1-z}{2}\right)\hat{x} + \hat{z}, \\ &= \bar{\kappa}\frac{1-z_0}{(1+z_0)\xi_0}\hat{x} - \bar{\kappa}\frac{\hat{z}}{\xi_0}\hat{x} + \hat{z} = \bar{\kappa}\frac{1-z_0}{(1+z_0)\xi_0}\hat{x} + \hat{z}, \end{aligned}$$

where the last line follows because the product of two small changes,  $\hat{z}\hat{x} \approx 0$ .  $\kappa$  is the PC defined in terms of percentage deviations from the steady state. Let  $z = z_0$  so that  $p_0 = \bar{p}_0$ . Then

$$\begin{aligned} \kappa &\equiv \frac{(\bar{p} - \bar{p}_0)/\bar{p}_0}{(\bar{x} - \bar{x}_0)/\bar{x}_0} = \frac{\bar{x}_0}{\bar{p}_0}\xi \left( \frac{1 - F(\bar{\alpha})}{\int_0^{\bar{\alpha}} \alpha \, dF(\alpha)} \right), \\ &= \frac{(1-z_0)/2}{(1+z_0)\xi_0/2}\bar{\kappa} = \frac{1-z_0}{1+z_0}\bar{\kappa}, \end{aligned}$$

where  $\xi_0 = 1$ . As expected, the PC slope is indeed the PC slope, appropriately defined. Note that with a flat PC we have  $\kappa \approx 0$ , and so output gaps do not move inflation, while the supply shock  $\hat{z}$  does.

Furthermore, we can write the PC in terms of structural shocks directly as

$$\hat{\pi} = \hat{\xi}(1 - F(\bar{\alpha})) + \hat{z}. \quad (\text{B.1})$$

The aggregate price level given  $z$  and  $\xi$  is

$$\begin{aligned}\bar{p} &= \int_0^{\bar{\alpha}} \frac{\xi_0(1+z)}{2} dF(\alpha) + \int_{\bar{\alpha}}^1 \frac{\xi(1+z)}{2} dF(\alpha), \\ &= \left(\frac{1+z}{2}\right) (\xi_0 + (\xi - \xi_0)(1 - F(\bar{\alpha}))), \\ &= \left(\frac{1+z}{2}\right) \xi_0 \left(1 + \widehat{\xi}(1 - F(\bar{\alpha}))\right).\end{aligned}$$

Dividing by the initial price level  $\bar{p}_0$  and substituting  $\hat{z}$ ,

$$\begin{aligned}\frac{\bar{p}}{\bar{p}_0} &= \left(\frac{1+z}{1+z_0}\right) \left(1 + \widehat{\xi}(1 - F(\bar{\alpha}))\right), \\ &= (1 + \hat{z}) \left(1 + \widehat{\xi}(1 - F(\bar{\alpha}))\right), \\ &= 1 + \widehat{\xi}(1 - F(\bar{\alpha})) + \hat{z} + \widehat{\xi}\widehat{\xi}(1 - F(\bar{\alpha})).\end{aligned}$$

Using that the product of hat variables is zero, the last term is annihilated. We therefore have

$$\frac{\bar{p}}{\bar{p}_0} - 1 = \widehat{\xi}(1 - F(\bar{\alpha})) + \hat{z},$$

and therefore we have  $\widehat{\pi} = \widehat{\xi}(1 - F(\bar{\alpha})) + \hat{z}$ . □

## B.2 Proof for Section 4

LEMMA 4 (PBE with Flexible Prices and Marginal Costs). *The flexible price  $\{p_s\}$  is consistent with some PBE if and only if*

$$z \geq \bar{z} \equiv \frac{1 - \alpha\xi_H/\xi_L}{\alpha(\xi_H/\xi_L - 2) + 1}.$$

The average prices  $\bar{p}_s$  and demands  $\bar{y}_s$  in state  $s$  can be written

$$\bar{p}_s = \int_0^{\bar{z}} \xi_0 \frac{1+z}{2} dG(z) + \int_{\bar{z}}^1 \xi_s \frac{1+z}{2} dG(z), \quad (\text{B.2})$$

$$\begin{aligned} \bar{y}_s = & \int_0^{\bar{z}} \left( \alpha \left[ 1 - \frac{1+z}{2} \frac{\xi_0}{\xi_s} \right] + (1-\alpha) \left[ \frac{1-z}{2} \right] \right) dG(z) \\ & + \int_{\bar{z}}^1 \frac{1-z}{2} dG(z). \end{aligned} \quad (\text{B.3})$$

For symmetry, we define the PC comparing the outcomes in the high and low states, and therefore, the slope of the PC is

$$\bar{\kappa} = \frac{\bar{p}_H - \bar{p}_L}{\bar{y}_H - \bar{y}_L} = \left( \frac{\xi_H \xi_L}{\alpha \xi_0} \right) \frac{\int_{\bar{z}}^1 (1+z) dG(z)}{\int_0^{\bar{z}} (1+z) dG(z)}. \quad (\text{B.4})$$

Compared with the baseline model, we aggregate using  $G$  instead of  $F$ ; the model behaves similarly.<sup>15</sup>

*Proof of Lemma 4.* Incentive compatibility for the flexible price equilibrium requires

$$\begin{aligned} \left( \frac{\xi_L(1-z)}{2} \right) \left( \frac{1-z}{2} \right) \geq & \left( \frac{\xi_H(1+z) - 2\xi_L z}{2} \right) \left( \alpha \left( 1 - \left( \frac{1+z}{2} \right) \frac{\xi_H}{\xi_L} \right) \right. \\ & \left. + (1-\alpha) \left( 1 - \left( \frac{1+z}{2} \right) \right) \right). \end{aligned}$$

Simplifying,

$$\begin{aligned} \xi_L \frac{(1-z)}{2} \left( \frac{1-z}{2} \right) \geq & \left( \frac{\xi_H(1+z) - 2\xi_L z}{2} \right) \left( \alpha \left( \frac{2 - (1+z)\xi_H/\xi_L}{2} \right) \right. \\ & \left. + (1-\alpha) \left( \frac{1-z}{2} \right) \right) \\ \xi_L(1-z)(1-z) \geq & (\xi_H(1+z) - 2\xi_L z) (\alpha(2 - (1+z)\xi_H/\xi_L) \\ & + (1-\alpha)(1-z)). \end{aligned}$$

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<sup>15</sup>As an aside, note that in this setting a supply shock that increases the distribution of  $z$  would increase the fraction of flexible price firms, which would, all else being equal, steepen the PC. Because this is not the main point of our paper, we do not emphasize this result, but leave it to later work to further investigate this prediction.

Letting  $\delta = \xi_H/\xi_L$  and dividing both sides by  $\xi_L$ ,

$$(1-z)(1-z) \geq (\delta(1+z) - 2z)(\alpha(2 - (1+z)\delta) + (1-\alpha)(1-z))$$

$$(1-z)(1-z) \geq (\delta(1+z) - 2z)((1-z) + \alpha(1+z)(1-\delta)).$$

Note that  $\delta(1+z) - 2z > 1-z$  and  $\delta > 1$  so that  $1-\delta < 0$ . Then, rearranging, we have

$$\alpha(1+z)(\delta-1)(\delta(1+z) - 2z) \geq (\delta(1+z) - 2z)(1-z)$$

$$-(1-z)(1-z)\alpha \geq \frac{1-z}{\delta + \delta k - 2z} = \bar{\alpha}.$$

Inverting the requirement (if  $z$  varies), then the cutoff for marginal cost solves

$$\alpha(\delta + \delta k - 2z) \geq 1-z, \implies (\alpha(\delta - 2) + 1)k \geq 1 - \alpha\delta.$$

Note that  $1 + \alpha\delta > 1 + \alpha > 2\alpha$ . Hence,  $\alpha(\delta - 2) + 1 > 0$ , and so we have  $z \geq \frac{1-\alpha\delta}{\alpha(\delta-2)+1} = \bar{z}$ .  $\square$

### Appendix C. Real Rigidities in the NK Model

A possible way to generate a flat short-term PC is using various real rigidities.  $\kappa$  and  $\lambda$  are linked to each other by a proportionality coefficient:

$$\kappa \equiv e \cdot \lambda, \tag{C.1}$$

where  $e$  measures how marginal costs comove with the output gap:  $\widehat{m}c_t = e \cdot \widehat{x}_t$ .  $\widehat{m}c_t$  denotes deviations in marginal costs (or equivalently, deviations in firms' desired markup). The parameter  $e$  is determined by real rigidities.

Many real rigidities show up in  $\lambda$ , while some (like sticky wages) show up in  $e$ . Specifically, high degrees of real rigidity in the mapping from the output gap to marginal costs can deliver a low value of the parameter  $e$  (a low elasticity of marginal costs to the output gap). This raises the question of whether  $\lambda$  could be large while  $\kappa$  is small in the context of the NK model, the issue that we bring up. As previewed, because empirical estimates of both  $\kappa$  and  $\lambda$  (separately)

are small, real rigidities do not present a plausible resolution to the puzzle we highlight. In other words, the empirical evidence suggests that the culprit for the observed flat PC is  $\lambda$  and not  $e$ .

In a nutshell, the reason for this is strong evidence that marginal costs move, whereas prices remain largely fixed. To expand on this point, recall that the standard NKPC can equivalently be written in linearized form as

$$\hat{\pi}_t = \beta \mathbb{E}_t[\hat{\pi}_{t+1}] + \lambda \widehat{mc}_t = \lambda \sum_{s=0}^{\infty} \beta^s \mathbb{E}_t[\widehat{mc}_{t+s}]. \quad (\text{C.2})$$

The second equality follows by iterating forward. Hence, inflation is caused by changes in firms' marginal costs or desired markups. Importantly, the parameter  $\lambda$  measures how changes in marginal costs translate into changes in prices. In general,  $\lambda$  is a function of the degree of price stickiness, the elasticity of substitution across goods, the capital share in production, and real rigidities caused by, for example, fixed production costs or kinked consumer demand (i.e., Kimball).

Marginal costs can increase due to demand or supply shocks. In response to demand shocks, output gaps can increase marginal costs whenever there is curvature in production or labor supply, leading to an increase in wages or capital costs. In response to supply shocks, marginal costs can increase for a given level of production because of higher input costs or productivity shocks, or firms may have a higher desired price for a given marginal cost. When marginal costs increase due to an output gap, the PC is most often written as in (1).

In the NK model, therefore, to get a flat PC, either  $e$  or  $\lambda$  must be very small. The behavior of inflation is entirely determined by the behavior of marginal costs and how much inflation responds to marginal costs. A low comovement between inflation and output gaps can be the result of low comovement between marginal costs and output (i.e., a low  $e$ ) or a low comovement between prices and marginal costs (i.e., a low  $\lambda$ ). To the extent that marginal costs move sufficiently without output gaps, generating a flat PC requires a low responsiveness of prices to marginal costs.

In the textbook NK model, the equilibrium relationship between output gaps and marginal costs is given by  $e = \sigma^{-1} + \frac{\varphi^{-1} + \zeta}{1 - \zeta}$ , where  $\sigma$  is the elasticity of intertemporal substitution,  $\varphi$  is the Frisch

elasticity, and  $\zeta$  is the curvature of the production function (Galí 2015). For the plausible values of  $\sigma = 1$ ,  $\varphi = 1/5$ , and  $\zeta = 1/3$ , then  $e = 9$ , implying that  $\lambda$  is an order of magnitude *smaller* than  $\kappa$  in the standard NK model. An alternative textbook benchmark is a model with GHH (Greenwood–Hercowitz–Huffman) preferences and constant returns to scale, in which case  $e = \varphi^{-1}$ . Microlevel estimates typically find  $\varphi$  to be less than 0.5, whereas macrolevel estimates using aggregate variables find  $\varphi$  in the range of 2–4. In either case, a very low  $\kappa$  necessitates a very low  $\lambda$ .

Most importantly, both Hazell et al. (2022) and Del Negro et al. (2020) provide clear empirical evidence that, in the data, marginal costs fluctuate, with a very low pass-through to prices. Specifically, Hazell et al. (2022)’s second IV strategy relies on marginal costs providing enough exogenous variation to identify  $\kappa$  and  $\lambda$ . In particular, the estimation of  $\lambda$  is based on direct measures of marginal costs variation embodied in tradable prices, which are used as inputs of production for nontradables. Similarly, Del Negro et al. (2020) also find considerable levels of aggregate price rigidity, which they attribute to a low  $\lambda$ . Their model explicitly allows for the possibility that  $e$  could be estimated to be very small—for example, due to sticky wages. However, the estimation does not support the view that a flat PC is due to a weak comovement of marginal costs with output gaps. Indeed, they find that the comovement of all real variables and indicators of firms’ cost pressures has been remarkably stable since 1964, and therefore the flat PC is most likely caused by a low sensitivity of price changes to marginal costs (see the discussion on pp. 316–17).

Altogether, the evidence points to a flat PC that comes not from a low  $e$  but from a low  $\lambda$ .

## Appendix D. Standard Pricing Frictions

This section solves the baseline model from Section 3 with perfect information but with standard pricing frictions. We consider quadratic adjustment costs (Rotemberg 1982), contract frictions (Calvo or Taylor), and fixed adjustment costs. None of these standard settings produce a flat PC *as well as* significant responsiveness to supply shocks. This is due to the symmetry embedded in these models regarding the reasons for the stickiness. In these settings,  $\kappa$  and  $\lambda$  move together, as is the case in the NK model (for a given  $e$ ). With



standard frictions, a very flat PC requires very large exogenous frictions to change prices. With standard price-setting frictions, variations in inflation require implausibly large structural supply shocks, just as in the standard NK model. The intuition is straightforward: if it is costly to change prices, then it is costly to change prices in response to supply shocks as well as in response to demand shocks.

**Quadratic Costs.** Let the firm face quadratic costs to adjust prices from  $p_0$  to  $p$ , given by  $\frac{\varphi}{2}(p - p_0)^2$ . Let  $p_0 = \frac{1-z}{2}$  be the base price. The firm maximizes

$$(p - z\xi)(1 - p/\xi) - \frac{\varphi}{2}(p - p_0)^2. \quad (\text{D.1})$$

We can summarize equilibrium as follows:

**LEMMA 5 (Quadratic Costs).** *With quadratic adjustment costs for prices, all firms set a price  $p^* = \xi \frac{1+z+\varphi p_0}{2+\varphi\xi}$ , and demand at each island is  $x = \frac{1-z+\varphi(\xi-p_0)}{2+\varphi\xi}$ . The PC slope in this economy is given by  $\kappa = \frac{2}{\varphi}$ .*

*Proof of Lemma 5.* Profits are  $p - z\xi - p^2/\xi + pz - \frac{\varphi}{2}(p - p_0)^2$ . The first-order condition is

$$1 + z - \frac{2}{\xi}p - \varphi(p - p_0) = 0, \quad (\text{D.2})$$

and solving for  $p$ , the optimal price is

$$p^* = \frac{1 + z + \varphi p_0}{\frac{2}{\xi} + \varphi} = \xi \frac{1 + z + \varphi p_0}{2 + \varphi\xi}$$

and total demand is

$$\bar{y} = 1 - \frac{1 + z + \varphi p_0}{2 + \varphi\xi} = \frac{1 - z + \varphi(\xi - p_0)}{2 + \varphi\xi}.$$

The PC is therefore given by

$$\kappa = \frac{\xi_H \frac{1+z+\varphi p_0}{2+\varphi\xi_H} - \xi_L \frac{1+z+\varphi p_0}{2+\varphi\xi_L}}{\left(1 - \frac{1+z+\varphi p_0}{2+\varphi\xi_H}\right) - \left(1 - \frac{1+z+\varphi p_0}{2+\varphi\xi_L}\right)} = \frac{2(\xi_H - \xi_L)}{\varphi\xi_H - \varphi\xi_L},$$

which simplifies finally to  $\kappa = \frac{2}{\varphi}$ . □

A flat PC corresponds to a very high  $\varphi$  (i.e., a high cost of adjusting prices). Asymptotically, if we want  $\kappa \rightarrow 0$ , we have  $\varphi \rightarrow \infty$ . In this setting, we cannot get inflation in response to cost shocks with a flat PC. We calculate

$$\frac{\partial p^*}{\partial z} = \frac{\xi}{2 + \varphi\xi}.$$

Thus, letting  $\varphi \rightarrow \infty$ , we have  $\lambda \rightarrow 0$ . If the PC is flat, a cost shock will not lead to a large change in prices. The intuition is simple: a flat PC corresponds to a high cost of changing prices. It's still costly to change prices, whether responding to demand or supply shocks, and so firms don't change prices much.

**Calvo-Taylor.** Now suppose a fraction  $1 - \varepsilon$  of firms cannot change their price. Thus, a fraction  $\varepsilon$  set their price to  $p^*$ , and the rest keep  $p_0$  (i.e., there are no strategical complementarities arising from monopolistic *competition* à la Dixit-Stiglitz). This setting could correspond to probabilistic price changes à la Calvo or staggered price setting à la Taylor. In either case, the fraction of firms that adjust their price (whether probabilistic or predetermined) is  $\varepsilon$ . The aggregate price and output are thus

$$\bar{p} = \varepsilon\xi(1+z)/2 + (1-\varepsilon)p_0, \quad \bar{y} = \varepsilon\frac{1-z}{2} + (1-\varepsilon)\left(1 - \frac{p_0}{\xi}\right).$$

LEMMA 6 (Calvo-Taylor). *With Calvo-Taylor frictions, the PC slope is  $\kappa = \frac{\varepsilon}{1-\varepsilon}\xi$ .*

*Proof of Lemma 6.* The PC slope is given by

$$\kappa = \frac{\varepsilon(\xi - \xi_0)(1+z)/2}{(1-\varepsilon)\left(\frac{p_0}{\xi_0} - \frac{p_0}{\xi}\right)} = \frac{\varepsilon}{1-\varepsilon} \frac{\xi\xi_0(1+z)}{2p_0}.$$

Since  $p_0 = \xi_0(1+z)/2$ , this simplifies to  $\kappa = \frac{\varepsilon}{1-\varepsilon}\xi$ .  $\square$

A flat PC corresponds to a very low  $\varepsilon$  (i.e., a low probability of price adjustment). Asymptotically, if we want  $\kappa \rightarrow 0$ , we have  $\varepsilon \rightarrow 0$ . Again, we cannot get inflation in response to cost shocks with a flat PC. We calculate

$$\frac{\partial \bar{p}}{\partial z} = \frac{\varepsilon\xi}{2}.$$

Letting  $\varepsilon \rightarrow 0$ , we have  $\lambda \rightarrow 0$ . If the PC is flat due to Calvo- or Taylor-style frictions, a cost shock will not lead to a large change in prices. The intuition is simple: a flat PC means few firms have the opportunity to change prices at all. If almost no firms can change prices, whether responding to demand shocks or supply shocks, aggregate prices won't change much in response to a cost shock.

**Fixed Costs.** Suppose firms pay a fixed cost  $k_i \in [\underline{k}, \bar{k}]$  to adjust prices, with costs distributed according to a CDF  $F$ . Adjusting firms choose  $p^* = \frac{\xi(1+z)}{2}$ , whereas not adjusting yields demand  $x = 1 - p_0/\xi$ , for a profit  $d_0 = (p_0 - z\xi)(1 - p_0/\xi) = p_0(1+z) - z\xi - p_0^2/\xi$ . A firm will adjust prices whenever

$$d^* \geq d_0 \implies k_i \leq k^*(\xi) \equiv \xi(1-z)^2/4 - (p_0(1+z) - z\xi - p_0^2/\xi).$$

Thus, the fraction of firms adjusting will be  $F(k^*)$ .

LEMMA 7 (Fixed Costs). *With fixed costs of adjusting prices, the PC slope in this economy is*

$$\kappa = \frac{F(k^*(\xi))}{1 - F(k^*(\xi))} \left( \frac{\xi(\xi - \xi_0)(1+z)}{1+z - \xi_0} \right). \quad (\text{D.3})$$

*Proof of Lemma 7.* Recall that  $p_0 = \frac{\xi_0(1+z)}{2}$ . Hence

$$\begin{aligned} k^*(\xi) &= \xi(1-z)^2/4 + p_0^2/\xi + z\xi - p_0(1+z), \\ &= \frac{\xi}{4}(1-z)^2 + \frac{\xi_0^2(1+z)^2}{4\xi} + z\xi - \frac{\xi_0(1+z)^2}{2}, \\ &= \frac{1}{4} \left( \xi(1-z)^2 + \frac{\xi_0^2(1+z)^2}{\xi} \right) - \frac{\xi_0(1+z)^2}{2} + z\xi, \end{aligned}$$

and we have

$$\begin{aligned} \frac{dk^*(\xi)}{d\xi} &= \frac{(1-z)^2}{4} - \frac{1}{4} \frac{\xi_0^2(1+z)^2}{\xi^2} + z \\ &= \frac{1}{4} \left( (1-z)^2 - \frac{\xi_0^2(1+z)^2}{\xi^2} \right) + z. \end{aligned}$$

Thus,  $k^*(\xi_0) = 0$  and is the global minimum. The average price is

$$\bar{p} = F(k^*(\xi)) \frac{\xi(1+z)}{2} + (1 - F(k^*(\xi)))p_0,$$

and the level of output is

$$\bar{y} = F(k^*(\xi)) \frac{1-z}{2} + (1 - F(k^*(\xi))) \left(1 - \frac{p_0}{\xi}\right).$$

Hence, we can write  $\kappa$  as

$$\begin{aligned} \kappa &= \frac{F(k^*(\xi)) \frac{\xi(1+z)}{2} + (1 - F(k^*(\xi))) p_0 - p_0}{F(k^*(\xi)) \frac{1-z}{2} + (1 - F(k^*(\xi))) \left(1 - \frac{\xi_0}{2\xi}\right) - \frac{1-z}{2}} \\ &= \frac{F(k^*(\xi)) \left(\frac{\xi - \xi_0}{2}\right) (1+z)}{(1 - F(k^*(\xi))) \left(\frac{1+z - \xi_0}{2\xi}\right)} \\ &= \frac{F(k^*(\xi))}{1 - F(k^*(\xi))} \left(\frac{\xi(\xi - \xi_0)(1+z)}{1+z - \xi_0}\right). \end{aligned}$$

□

In this setting, we can get a flat PC from very small demand shocks or very large fixed adjustment costs. It is easy to show that  $\kappa$  is increasing in  $\xi$ . The numerator is increasing because  $\xi(\xi - \xi_0)$  is, and since  $k^*$  is increasing, so is  $F(k^*)$ . If  $k^* < \underline{k}$ , then no firms will adjust prices and the PC will be perfectly flat. The denominator is decreasing by the same argument. Hence, smaller shocks lead to a flatter PC as fewer firms adjust.

Suppose firms start with marginal cost  $z_0$ , which then changes to  $z$ . This implies a cutoff  $k^*(z)$ , which is a different cost threshold for price-adjusting firms.

**LEMMA 8 (Inflation with Fixed Costs).** *With fixed costs of adjusting prices and a shock to marginal costs,  $k^*(z) = \frac{\xi_0}{4} (z_0 - z)^2$ , which implies  $\frac{\partial \bar{p}}{\partial z} = F(k^*(z)) \frac{\xi}{2}$ .*

*Proof of Lemma 8.*  $k^*$  is defined as above. Now we modify  $p_0 = \frac{\xi_0(1+z_0)}{2}$ . Hence we have

$$\begin{aligned} k^*(z) &= \xi(1-z)^2/4 + p_0^2/\xi + z\xi - p_0(1+z), \\ &= \frac{\xi}{4}(1-z)^2 + \frac{\xi_0^2(1+z_0)^2}{4\xi} + z\xi - \frac{\xi_0(1+z_0)(1+z)}{2}, \end{aligned}$$

$$= \frac{1}{4} \left( \xi(1-z)^2 + \frac{\xi_0^2(1+z_0)^2}{\xi} \right) - \frac{\xi_0(1+z_0)(1+z)}{2} + z\xi.$$

To consider a cost shock, we set  $\xi = \xi_0$  to get

$$k^*(z) = \frac{1}{4} \left( \xi_0(1-z)^2 + \frac{\xi_0^2(1+z_0)^2}{\xi_0} \right) - \frac{\xi_0(1+z_0)(1+z)}{2} + z\xi_0 = \frac{\xi_0}{4} (z_0 - z)^2.$$

□

Note that  $k^*(\xi)$  is linear in  $\xi$ , while  $k^*(z)$  is quadratic in  $z$ . Thus, if shocks are small (percentages), then  $(z - z_0)^2$  is likely to be smaller than  $\xi$ , and thus for small shocks,  $k^*(z) < k^*(\xi)$ . This means that we are likely to get even less response to a comparably sized supply shock than to a demand shock. If few firms were adjusting in response to a demand shock, then few firms would be adjusting in response to a (comparable) cost shock. If  $z$  is near  $z_0$ , then the cutoff  $k^*$  is small, so few firms will adjust. Thus, it is completely plausible to have no response in this case as well. If  $k^* < \underline{k}$ , then no firms will adjust prices in response to a change in  $z$ .

## Appendix E. Foundations for the Demand Shock

### E.1 Idiosyncratic Preference Shocks

To allow for imperfect information about the aggregate discount rate, we introduce idiosyncratic preference shocks. All consumers are perfectly informed about their own preference shock but do not observe the aggregate preference shock. The aggregate preference shock determines the price of the bond  $Q$  (pinned down, in equilibrium, by monetary policy).

Specifically, as in the body of this paper, let  $\theta_H$  denote the *aggregate* high state and  $\theta_L$  denote the *aggregate* low state. Each consumer's individual  $\theta_j$  is subject to an idiosyncratic component  $u_j \sim N(\mu_u, \sigma_u^2)$ :

$$\log \theta_j = \log \theta_s + u_j,$$

where  $\mu_u$  is the expectation of the idiosyncratic shock required for  $\xi_0 = 1$ . As in the body, a fraction  $\alpha$  of consumers are Insiders and

know the realization of the aggregate state, and a fraction  $1 - \alpha$  are Outsiders and do not know the realization of the aggregate state (but update their beliefs conditional on their idiosyncratic  $\theta_j$ ).

The results in the body of this paper hold true in this setup. Given the linearity of demand, it is straightforward to aggregate individual demands. The flexible price equilibrium replicates the results of perfect information benchmark, and Outsiders learn the aggregate shock from the price of the firm. In the sticky price equilibrium, we need to check the firms' incentive compatibility constraints, which are now affected by consumer learning from their own signals. This shifts Outsiders' demand toward the realized shock. However, similar to the model in the body, one can show that there is a cutoff in  $\alpha$ , bounded away from zero, for which sticky prices are an equilibrium.

## *E.2 Shocks to Future Income*

A shock to future endowments can be used to microfound the main model. Here, we provide a general equilibrium setting that shows how to write this microfoundation. Uninformed consumers know their preferences, but they do not know their future income; this setting provides an isomorphism to the main model.

### *E.2.1 Consumers*

Let consumers have utility

$$c - \frac{1}{2}c^2 - l + \beta V(C),$$

where  $c$  and  $C$  represent consumption and  $l$  is labor supply and  $V$  is a strictly increasing and concave function. The budget constraint is

$$pc + QC = d + wl + QE,$$

where  $w$  is the wage,  $Q$  is the bond price,  $d$  is the firm profit (dividend), and  $E$  is the future endowment. Let  $\mu$  denote the Lagrange multiplier. Household optimization yields

$$1 - c = \mu p, \tag{E.1}$$

$$1 = \mu w, \tag{E.2}$$

$$\beta V'(C) = Q\mu. \tag{E.3}$$

Notice that we have  $\mu = \frac{1}{w}$  and  $\mu = \frac{\beta V'(C)}{Q}$ . Define

$$\theta \equiv V'(C),$$

which is endogenous (we will pin it down soon). Notice that we therefore have

$$\mu = \frac{\beta\theta}{Q} \implies \mu = \frac{1}{\xi},$$

as we defined the demand shock in our paper. As before, we have

$$c^* = 1 - \frac{p}{\xi}.$$

### *E.2.2 Firms*

Firms have productivity  $A$  so  $y = Al$ . Thus, the marginal cost of producing  $y$  is  $\frac{w}{A}$  because producing  $y$  units requires  $1/A$  units of labor. Let  $z \equiv 1/A$ . From above we have  $w = \frac{1}{\mu} = \xi$ , and therefore we have marginal costs

$$\frac{w}{A} = z\xi,$$

just as in our model. The firm profit is

$$d = y(p - z\xi),$$

and the labor bill is

$$wl = \frac{wy}{A} = ywz = yz\xi.$$

### *E.2.3 Household Collective and Equilibrium*

We suppose that consumers belong to a household that distributes profits at the end of the period. The household collective receives  $d$  and then distributes the total dividend to each consumer in the household. This is a trivial problem in a flexible price equilibrium. In that case,  $c = y$  for each consumer, and so  $pc = d + wl$  and  $C = E$ .

Now consider a sticky price island. Let  $c_0$  and  $c_1$  denote consumption for the uninformed and informed. Let the household collective distribute dividends so that

$$pc_0 = d_0 + wl, \quad pc_1 = d_1 + wl,$$

i.e., each consumer type receives a portion of firm profits so that present earnings (wages plus profits) are sufficient to cover consumption. Since the firm sells  $\alpha c_1 + (1 - \alpha)c_0$  units, the dividend distribution scheme is feasible. Thus,  $C = E$  for each agent. And that means that, indeed,

$$\theta = V'(E)$$

in equilibrium for each agent. Thus, we can let variations in  $E$  drive variations in  $\theta$ .

## Appendix F. General Equilibrium Framework

This section lays down a general equilibrium framework in which our model of price stickiness can be embedded. We have two goals. The first is to clarify that the earlier results can be obtained in a model with labor supply (and no endowments). The second is to clarify that the earlier results can be obtained in a model in which money plays an essential role. The setup's ingredients are standard. However, putting the pieces together is quite involved. Therefore we start the model description with a preview. We subsequently fully describe every piece of the model.

### *F.1 Preview*

The setup is based on the foundational papers by Lagos and Wright (2005) and Lucas and Stokey (1987). As in Lagos and Wright (2005), we exploit quasi-linearity and periods that are divided in a day and a night to be able to handle agent (informational) heterogeneity. As in Lucas and Stokey (1987), we use a cash-in-advance model with credit and cash goods. The presence of credit goods is key for specifying trading in goods markets with partially informed consumers.

The population of the economy is composed of a unit mass of households. These households own a unit mass of firms, which operate in different and segmented geographic locations called islands. There is a unit mass of islands, and on each island there is a single firm.

Households are divided into workers and consumers. Workers supply labor, while consumers shop for consumption goods.



As in Lagos and Wright (2005), each period is divided into two subperiods: a day and a night. All the action of interest takes place during the day; the night is simply introduced as a technical device to close the model. Trading of credit goods takes place during the day; trading of cash goods takes place during the night.

The exogenous aggregate state of the economy is given by a preference shock  $\theta$ , which is the discount factor between the day and the night, and by firms' level of productivity  $A$ . As in most of the literature, the preference shock is a modeling device to generate fluctuations in nominal aggregate demand. As in the simple model presented in the paper, a key assumption of our setup is that there is household heterogeneity in the information about the aggregate shocks. Some households may be imperfectly informed about the value of discount factor at night.<sup>16</sup> We model this by making the sharp assumption that a fraction of households is perfectly informed about the realization of the shock, and the complement is uninformed about the realization of the shock. As discussed in the benchmark model, consumers' knowledge of firms' productivity is irrelevant in equilibrium.

Firms, by assumption, are informed about the preference shock as well as their productivity. We motivate this simplifying assumption by a story in which firms are able to aggregate consumer demand via goods market trading. So long as a nonzero mass of each firm's consumers are informed, their demand then reveals the aggregate preference shock to firms. To simplify the exposition, here we simply assume that firms are informed right from the start. On the other hand, imperfectly informed consumers can learn by looking at firms' prices. Notice that our informational assumptions force us to move away from monopolistic competition (or other forms of centralized goods markets). In fact, firms and consumers play a sequential game. Consumers and firms meet in decentralized locations. Each firm posts a price; consumers observe the price and then post their demand.

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<sup>16</sup>One can also think about this shock representing a shift in marginal utility at night. Under this interpretation, the assumption is that, during the day, imperfectly informed households do not receive full information about marginal utility at night.

The central bank controls money supply, which determines relative price between the night and day. The central bank uses a rule to determine its policy. This rule depends on deviations of inflation from a target and on the output gap.

## *F.2 Full Model*

**Population and Geography.** The economy is populated by households, firms, and a central bank. The geography is given by a unit mass of islands and a mainland. Each island is populated by a continuum of households of mass one and is served by a single monopolistic firm. The mainland is visited by all consumers in the economy at given dates and is served by a competitive representative firm. Households are divided into workers and consumers.

**Time Structure.** Time is discrete. Similar to Lagos and Wright (2005), periods are divided into two subperiods, called day and night. Following their notation, we will denote day variables in lowercase and night variables in uppercase. Subperiods are indexed by  $\tau$ :  $\tau = 0$  signifies the day, and  $\tau = 1$  signifies the night. (However, to simplify the notation, we skip  $\tau$  notation whenever possible.) Periods are indexed by  $t$  and run from  $t = 0$  to infinity.

**Goods Markets.** We start by describing daytime trading in the decentralized market. Each mass of consumers are served by a price-setting monopolist (on a given island), which sells good  $c$  at a nominal price  $p$ . These decentralized goods are bought on credit.

We now describe the functioning of the nighttime, centralized, market. At night, all consumers are sent to the mainland. There, they consume an aggregate good  $C$ , produced by a competitive firm and sold at an aggregate nominal price  $P$ . We also refer to this aggregate price  $P$  as the night price level. This good is sold in exchange for cash.

**Labor Markets.** Labor markets are open during both the day and the night. During the day, workers supply labor in a centralized labor market. Local firms hire workers from this centralized market. At night, labor is supplied in the mainland. Both day and night markets are competitive. Daytime labor is denoted  $l$ ; nighttime labor is denoted  $L$ . We denote wages as  $w$  and  $W$ , respectively.

**Credit, Financial, and Money Markets.** During the day, all transactions take place on credit. Consumers buy consumption

goods on credit, workers bring back wages, and firms pay profits (the firm is owned by local households).

At night, goods are bought in cash. (Labor is supplied on credit.)

The money market opens only at (the end of the) night. Similar to Lucas and Stokey (1987), all credit transactions are settled at this moment. A (long-term) bond is available across periods. These are trades in exchange of money holdings for the next period  $t + 1$ . Long-term bonds and cash holdings are denoted  $B$  and  $M$ , respectively.

**Exogenous Aggregate State.** The exogenous aggregate state is given by the realizations of a preference shock  $\theta_t$  and aggregate productivity  $A_t$ . We specify the processes for these shocks below.

**Central Bank.** The money supply set by the central bank determines the price level during the night  $P$ .

**Information Structure.** Consumers are heterogeneous in terms of the information they possess. There are two types of consumers: Insiders (informed consumers) and Outsiders (uninformed consumers). Insiders are perfectly informed about the state  $\{\theta_t, A_t\}$ ; Outsiders are uninformed about the state but know the probability distribution, and may draw inferences from the price set by the firm with which they trade. The fraction  $\alpha \in [0, 1)$  of Insiders on a particular island varies across islands. We assume the distribution of  $\alpha$  is given by a CDF  $F$  whose support is not a singleton and has the property that

$$\lim_{\alpha \rightarrow 1} F(\alpha) = 1.$$

That is, the fraction of islands on which all consumers are Insiders is 0. All other agents in the economy have perfect information.

All of the above is common knowledge.

**Household Optimization.** We start by presenting an inner problem of the household. In this problem, the household solves for all variables that trade in credit. This is the “day-to-night” problem where the action happens. (The outer problem is presented below.) In contrast to the setting in the body of this paper, and without loss of generality, here we suppose that time discounting with  $\beta$  occurs only across periods (i.e., the outer problem) rather than within the period (across subperiods).

We index a typical household by  $j$ . The inner problem at date  $t$  consists in solving

$$\max_{c_t, l_t, L_t} \mathbb{E}_{j\tau} \left[ \left( u(c_t) - l_t \right) + \theta_t \left( U(\bar{C}) - L_t \right) \right],$$

where choices variables have been defined above. The variable  $\bar{C}$  denotes a fixed allocation of the nighttime consumption good. Since this good is traded in cash, its consumption is fixed in the inner problem (the outer problem will determine this quantity). The random variable  $\theta_t$  determines the discount factor between the day and the night. Following the previous sections, we specify the process for  $\theta_t$  to follow an i.i.d. binary Markov chain with two values,  $\theta_L$  and  $\theta_H$ , with  $Pr(\theta_L) = Pr(\theta_H) = 1/2$  and  $\mathbb{E}[\theta_t] = \theta < 1$ . The realization  $\theta_H$  corresponds to the high state, and the realization  $\theta_L$  corresponds to the low state. The household values daytime consumption relatively more in the high state (and hence demand is higher than in the low state). Hence, the realizations are such that  $\theta_L > \theta_H$ .<sup>17</sup> The utility functions  $u(\cdot)$  and  $U(\cdot)$  are assumed to be twice continuously differentiable on  $\mathbb{R}^{++}$ , strictly increasing, and strictly concave. Below, we make an assumption on  $u(\cdot)$  such that the monopolist's problem has a solution.<sup>18</sup> We assume that there is a value of  $C$  such that  $U'(C) = 1/\beta$ . The expectation operator is indexed by  $j$  to signify the household member's information set at the time they make a choice.

This problem is subject to a constraint given by

$$p_t c_t + P_t \bar{C} = d_t + w_t l_t + W_t L_t, \quad (\text{F.1})$$

where prices have been defined above and  $d_t$  are profits.

Denoting by  $\lambda_t$  the Lagrange multiplier of the constraint (F.1), the first-order condition for daytime consumption  $c$  is

$$u'(c_t) = \mathbb{E}_{j\tau} [\lambda_t p_t].$$

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<sup>17</sup>The model allows for richer specifications of the exogenous process for the state, such as persistent Markov chains and AR(1). (To simplify the notation of this general equilibrium framework, we omit the subscript  $s$  to denote the state as in the previous sections and simply use the notation  $\theta_t$ .)

<sup>18</sup>For tractability, the body uses quadratic utility. Here in the general equilibrium framework we aim to show that this particular restriction is not needed to find a general equilibrium solution.

It is important to emphasize that, depending on the index  $j$ , this condition may be taken under imperfect information. Indeed, it defines the choice, in a decentralized market, by a consumer that can be an Outsider. (Insiders have full information about the product  $\lambda_t p_t$ .) Notice however that Outsiders observe the price of the firm they meet,  $p_t$ , and hence the expectation conditional on this price. Therefore, it can be taken out of the expectation operator. We obtain the following set of first-order conditions:

$$\begin{aligned} u'(c_t) &= p_t \mathbb{E}_{j\tau} [\lambda_t] \\ 1 &= \lambda_t w_t \\ \theta_t &= \lambda_t W_t. \end{aligned}$$

(The remaining optimality conditions are taken under perfect information, since they involve choices in centralized markets.)

From the second equation we observe that  $\lambda_t = 1/w_t$ . Further manipulating the equations above, we can summarize the set of first-order conditions as

$$u'(c_t) = p_t \mathbb{E}_{j\tau} \left[ \frac{\theta_t}{W_t} \right] \tag{F.2}$$

$$\frac{1}{w_t} = \theta_t \frac{1}{W_t}. \tag{F.3}$$

We continue by presenting the outer problem of the household. This is the problem solved from one day to the next. This problem will give rise to an explicit role for money and hence allows us to define the monetary policy instrument.

Define

$$\mathcal{U}(c_t, l_t, C_t, L_t) = \left( u(c_t) - l_t \right) + \theta_t \left( U(C_t) - L_t \right).$$

In the outer problem, the household needs to solve

$$\max_{c_t, l_t, C_t, L_t, M_t, B_t} \mathbb{E}_{j\tau} \left[ \sum_{t=0}^{\infty} \beta^t \mathcal{U}(c_t, l_t, C_t, L_t) \right],$$

which involves choosing infinite sequences of consumption, labor supply, money, and bond holdings subject to

$$p_t c_t + P_t C_t + B_t + M_t = w_t l_t + W_t L_t + M_{t-1} + T_t + (1 + i_t^{LT}) B_{j,t-1} + d_t, \quad (\text{F.4})$$

where  $i_t^{LT}$  is a long-term nominal interest rate, and  $T_t$  is a lump-sum cash transfer set by the central bank. Purchases of the cash good are also subject to a cash-in-advance (CIA) constraint

$$P_t C_t \leq M_{t-1} + T_t. \quad (\text{F.5})$$

Denoting by  $\chi_t$  the multiplier on the budget constraint (F.4) and by  $\psi_t$  the multiplier on the CIA constraint (F.5), we get the set of first-order conditions

$$\beta^t u'(c_t) = \mathbb{E}_{j\tau} [\chi_t p_t] \quad (\text{F.6})$$

$$\beta^t = \chi_t w_t \quad (\text{F.7})$$

$$\beta^t \theta_t U'(C_t) = (\chi_t + \psi_t) P_t \quad (\text{F.8})$$

$$\beta^t \theta_t = \chi_t W_t \quad (\text{F.9})$$

$$\chi_t = \mathbb{E}_t [\chi_{t+1} + \psi_{t+1}] \quad (\text{F.10})$$

$$\chi_t = (1 + i_{t+1}^{LT}) \mathbb{E}_t [\chi_{t+1}], \quad (\text{F.11})$$

where it is important to notice the presence of two different expectation operators, the daytime expectation operator  $\mathbb{E}_{j\tau}[\cdot]$  (conditional on consumer  $j$ 's information), and the nighttime expectation operator  $\mathbb{E}_t[\cdot]$  (conditional on full information, which is available in the centralized market).

From (F.7) and (F.9), we observe that  $\chi_t = \beta^t/w_t$  and  $\chi_t = \beta^t \theta_t/W_t$ . Thus,

$$\frac{1}{w_t} = \theta_t \frac{1}{W_t},$$

which is the same as (F.3). Also, plugging in the expression for  $\chi_t$  obtained from (F.9) into (F.6), we get

$$u'(c_t) = p_t \mathbb{E}_{j\tau} \left[ \frac{\theta_t}{W_t} \right], \quad (\text{F.12})$$

which is the same as (F.2).

The remaining conditions, determining the demand for money and bonds, can be simplified as follows. Equation (F.8), one period forward, is  $\beta^{t+1}\theta_{t+1}U'(C_{t+1}) = (\chi_{t+1} + \psi_{t+1})P_{t+1}$ . Solving for  $\chi_{t+1} + \psi_{t+1}$ , and using the expression for  $\chi_t$ , Equation (F.10) becomes

$$\frac{\theta_t}{W_t} = \beta \mathbb{E}_t \left[ \frac{\theta_{t+1}}{P_{t+1}} U'(C_{t+1}) \right]. \quad (\text{F.13})$$

Finally, Equation (F.11) is equivalent to

$$\frac{\theta_t}{W_t} = \beta (1 + i_{t+1}^{LT}) \mathbb{E}_t \left[ \frac{\theta_{t+1}}{W_{t+1}} \right]. \quad (\text{F.14})$$

**Production.** All firms in the economy have a linear technology and produce using only labor. Within every period, a monopolist of the decentralized market produces  $c$  according to the production function  $c_t = A_t l_t$ . The real marginal cost is  $z_t \equiv 1/A_t$ . Following the previous sections, we specify the process for  $z_t$  to follow an i.i.d. binary Markov chain with two values,  $z_L$  and  $z_H$ , with  $Pr(z_L) = Pr(z_H) = 1/2$ .

The competitive firm produces  $C$  according to the production function  $C_t = L_t$ , where productivity has been normalized to 1.

**Game in the Decentralized Market.** The equilibrium notion for the game played between consumers and firms is the one described in full detail in the body of this paper. Below we shall prove that this setup is tractable in the following sense: Any equilibrium of this game is part of a general equilibrium for the whole economy.

**Central Bank.** The central bank sets the money supply  $M_t^S$ . An increase of the money supply (away from its steady-state value) is expansionary since it increases aggregate demand, and vice versa. The central bank behaves by adjusting money supply as a function of inflation and the output gap, according to the following rule:

$$M_t^S = M_0 \left( \hat{\pi}_t \right)^{-\phi_\pi} \left( \hat{x}_t \right)^{-\phi_x}, \quad (\text{F.15})$$

where  $M_0$  is the natural level of the money supply;  $\hat{\pi}_t$  is inflation, defined as the percentage deviation of the price level away from steady state  $\bar{p}_0$ :  $\hat{\pi}_t = \frac{\int \bar{p}_t dF(\alpha) - \bar{p}_0}{\bar{p}_0}$ ; and  $\hat{x}_t$  is the output gap, defined

as the percentage deviation of aggregate output from the natural level  $y^n$ :  $\hat{x}_t = \frac{\int y_t dF(\alpha) - y^n}{y^n}$ . Below we show that this policy rule can be expressed as a rule for a short-term interest rate rate.

We are finally in a position where we can define a general equilibrium for the economy.

**Definition of Equilibrium.** A (general) equilibrium of this economy is given by consumption allocations, labor supply, bond holdings, and money demand (for each household)  $\{c_t, C_t, l_t, L_t, B_t, M_t\}$ , labor demand (for each firm)  $\{l_{jt}^D, L_t^D\}$ , profits  $\{d_t\}$ , money supply  $\{M_t^S\}$ , nominal transfers  $\{T_t\}$ , nominal prices  $\{p_t, P_t\}$ , nominal wages  $\{w_t, W_t\}$ , and long-term nominal interest rates  $\{1 + i_t^{LT}\}$ , for all  $t$ , such that

- households' conditions for optimality and corresponding constraints are satisfied;
- the price-setting game is solved as specified above;
- the representative firm maximizes profits taking the price as given;
- the CB sets money supply as specified by the rule above; and
- goods, labor, bonds, and money markets clear.

**General Equilibrium Characterization.** First, we conjecture that  $C_t$  is constant in equilibrium. If so, then the price of this good is pinned down by the cash-in-advance constraint. We denote this constant  $C_t = \bar{C}$ . Second, we conjecture that  $M_t = M_t^S$ , for all  $t$ . Then,  $P_t = M_t/\bar{C}$ .

By the optimality condition for the production of the representative firm, the nominal wage  $W_t = P_t$  (since productivity is normalized to 1). Thus,

$$P_t = W_t = \frac{M_t}{\bar{C}}. \quad (\text{F.16})$$

Now, taking Equation (F.13) and writing it as

$$\frac{\theta_t}{M_t} = \beta U'(\bar{C}) \mathbb{E}_t \left[ \frac{\theta_{t+1}}{M_{t+1}} \right]$$

reveals that as long as  $U'(\bar{C}) = 1/\beta$  and  $\theta_t/M_t$  is a martingale, Equation (F.13) is satisfied. A monotonic rule can be mapped



into a degree of monetary policy adjustment  $\gamma$ . Hence, we write the rule

$$\frac{1}{M_t} = \gamma \frac{1}{\theta_t} + (1 - \gamma) \frac{1}{M_0}.$$

According to this rule, when  $\gamma = 1$ , there is full adjustment ( $M_t = \theta_t$ ), and when  $\gamma = 0$ , there is no adjustment ( $M_t = M_0$ ). This rule can be written

$$\frac{\theta_t}{M_t} = \gamma + (1 - \gamma) \frac{\theta_t}{M_0}.$$

Taking the expectation of  $\theta_t/M_t$  shows, trivially, that this ratio is a martingale, and thus Equation (F.13) is satisfied.

A similar argument for  $i_t^{LT} = 1/\beta - 1$  shows that Equation (F.14) is satisfied.

Since this is a closed economy with a zero net supply of bonds, we can simply set  $B_t = 0$  for all households. It remains to check that the labor markets clear. The centralized market clears when each household supplies  $L_t = C_t$ . In the decentralized market, each household's labor supply is set to satisfy their respective budget constraints. Aggregating the budget constraint gives the economy's resource constraint, and from this one can establish that the labor market clears in each island. (Note that this implies that any equilibrium solution to the game played between firms and consumers is a general equilibrium. This ensures a tractable and isolated treatment of the game.)

Finally, set  $T_t = M_t - M_{t-1}$ . At this point, we are able to verify our money demand and centralized good consumption conjectures. This completes the characterization of the general equilibrium framework.

**Equivalence Results.** In order to understand the sense in which the program of the household admits an inner and an outer problem, notice first that the first-order conditions for  $c_t$  in both problems are the same (Equations (F.2) and (F.12)). Also, since the equilibrium in the outer problem requires  $L_t = C_t$ , and since  $W_t = P_t$ ,  $M_t = M_{t-1} + T_t$  and  $B_t = 0$ , then, setting  $E = \bar{C}$ , the budget constraints in both problems reduce to

$$p_t c_t = d_t + w_t l_t,$$

leading to the same choice of  $l_t$  in both problems. The following result has then just been established.

LEMMA 9. *The equilibrium allocations of  $c_t, l_t, L_t$  in the inner problem are the same as in the outer problem. Moreover, the equilibrium allocation  $C_t$  is an admissible endowment  $E$  of the inner problem.*

To obtain the simple, partial equilibrium model in the body, interpret the cash good as a numeraire good. Since the credit good and the cash good are purchased in subsequent periods (call them period 0 and period 1), the price  $P_t$  can be interpreted as the price of an asset traded at period 0 that pays one unit of the numeraire good in period 1. Denote this price  $Q_t$ . Then,  $Q_t = P_t$ .

In the simple model, the choice of  $C$  is determined by the budget constraint. Since households are heterogeneous in terms of their information and implied choice of  $c$  for each consumer, nothing guarantees that  $C$  is equal to  $E$  for each consumer. However, by linearity, one can verify that the aggregate quantity of  $C$  is indeed equal to  $E$  (i.e., markets clear).

Notice that  $M_t = E \cdot Q_t$ . So the rule (F.15) is

$$E \cdot Q_t = E \cdot Q_0 \left( \hat{\pi}_t \right)^{-\phi_\pi} \left( \hat{x}_t \right)^{-\phi_x},$$

which is

$$1 + i_t = (1 + i_0) \left( \hat{\pi}_t \right)^{\phi_\pi} \left( \hat{x}_t \right)^{\phi_x}.$$

In logs,

$$\log(1 + i_t) = \log(1 + i_0) + \phi_\pi \hat{\pi}_t + \phi_x \hat{x}_t.$$

Finally, the simple model can be written using two periods only, which allows to drop the  $t$  index and keep only the lowercase and uppercase notation for  $t = 0$  and  $t = 1$ .

Thereby, the following lemma establishing the alleged equivalence has been proven.

LEMMA 10. *The model presented in the body has the same equilibrium allocation of  $c_t$  as the full general equilibrium model. Also, the aggregate consumption of  $C$  in the simple model is equal to  $E = \bar{C}$ .*

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