Optimal Monetary Policy Under Menu Costs

Daniele Caratelli*   Basil Halperin[†]

May 14, 2025

Abstract

We analytically characterize optimal monetary policy in a multisector economy with menu costs and contrast it with optimal policy in the canonical New Keynesian model based on Calvo pricing. Following a sectoral productivity shock, supply-and-demand reasoning would suggest that the price level and output should move inversely. However, the textbook New Keynesian model would prescribe zero inflation, which provides a formal justification for the policy of inflation targeting. In contrast, under menu costs, inflation and output should indeed move inversely, rationalizing the practice of "looking through" sectoral shocks. We provide sharp intuition for this result: stabilizing inflation causes shocks to spill over across sectors, which needlessly increases the fraction of firms that must pay the menu cost. Finally, we show in a quantitative model that moving from inflation targeting towards optimal policy improves welfare by 0.32% in consumption-equivalent terms.

1 Introduction

Many central banks around the world have adopted some form of inflation targeting over the past three decades. The textbook formulation of the New Keynesian model provides theoretical grounding for such policies: in the Calvo formulation of the New Keynesian model, where firms are only randomly given the opportunity to change prices, optimal policy in response to efficient shocks is strict inflation targeting. This is true in the textbook one-sector New Keynesian model (Woodford 2003) as well as in heterogeneous multisector versions of the model, for an appropriately-defined price index (Rubbo 2023). The Calvo assumption of random price changes upon which these models are built is mathematically convenient, but arguably comes at the cost of realism. A natural but notoriously less tractable alternative is the "menu cost" model in which firms can *choose* to change their prices at any time, but must pay a fixed menu cost to do so.

We analytically and without linearization characterize optimal monetary policy in a multisector economy with menu costs and show that optimal policy ensures that inflation and output move inversely after sectoral productivity shocks. That is, following negative productivity shocks, inflation should be allowed to rise, and vice versa. We show this by developing a model in which the economy is made up of sectors, where firms are subject to sector-specific productivity shocks and can change their price at any point by paying a menu cost. In baseline parameterizations, optimal policy in response to such shocks is precisely nominal wage targeting: nominal wages should be stabilized, but inflation should not be. This is despite wages themselves being completely flexible. More generally, the optimal policy response to sectoral productivity shocks ensures that the nominal marginal costs of unshocked firms are not affected by shocks.

Intuition. The intuition for this result is that stabilizing inflation causes shocks to spill over across sectors and therefore leads the economy to incur unnecessary menu costs. Consider, for example, a positive productivity shock affecting only firms in sector 1. If the shock is sufficiently large, then it is efficient and desirable for firms in sector 1 to cut their *relative* prices, compared to firms in other sectors of the economy. Under a policy of inflation targeting, the overall price level must be unchanged. To simultaneously have the relative price fall *and* the price level be stable requires not only that sector-1 firms cut their nominal prices, but also that firms in all other sectors raise their nominal prices. As a result, *all* sectors are forced to adjust their prices and pay a menu cost.

A natural alternative – which we show to be optimal – is instead to simply allow firms in sector 1 to cut their nominal prices and to ensure that firms in other sectors do not want to adjust their prices. As a result, relative prices are correct, and *only* sector-1 firms must

pay a menu cost. Thus optimal policy economizes on wasteful menu costs compared to inflation targeting, while still achieving the efficient allocation. Optimal policy "looks through" the shock in the sense that *aggregate* inflation is allowed to adjust, instead of the central bank acting to ensure aggregate inflation is unaffected.

Firms only want to adjust their prices if their *nominal marginal costs* change, and so optimal policy seeks to ensure that nominal marginal costs do not change in unshocked sectors. In a baseline model where wages and productivity are the only factors affecting marginal cost, optimal policy stabilizes nominal wages, since this ensures marginal costs are unchanged for those firms whose productivity does not change. More generally, optimal policy causes inflation and output to move inversely: the positive productivity shock causes output to rise, and the price decrease in sector 1 causes aggregate inflation to fall. In contrast, inflation targeting would be optimal in the Calvo version of this example.[1]

Analytical model.   We begin in sections 2 and 3 with an off-the-shelf, two-period, multi-sector menu cost model and analyze a one-sector shock, as described above, which is the minimum necessary machinery to highlight the core economic logic. The framework is general and can allow "menu costs" to capture a broad conception of *fixed* costs of price adjustment, whether they be physical costs (Walmart workers walking around a store replacing price tags), optimization costs (a small business owner thinking about what price to set), or behavioral costs (consumers with a distaste for price changes).

We go on to show in sections 4 and 5 that the analytical logic generalizes to several extensions. We characterize optimal policy when shocks affect multiple sectors simultaneously and show that for a broad class of such shocks stabilizing the nominal marginal costs of unshocked firms continues to be optimal policy. We also extend the model to allow for production networks or for other forms of heterogeneity, and we show that optimal policy continues to feature countercyclical inflation.

Comparison to Calvo.   Our results in the menu cost model shed subtle new light on the standard Calvo model result: inflation targeting is optimal in the multisector Calvo model because *welfare losses from relative price dispersion are convex in the degree of dispersion*. This convexity of welfare costs makes it optimal to *smooth* price dispersion across sectors. It is better to have every sector change prices a little, than to have one sector change prices a lot. In contrast, the standard menu cost model has fixed, *nonconvex* costs of adjustment, so it is optimal to minimize the number of firms who do any price adjustment.

As a concrete example, consider again the case of a positive productivity shock affect-

---

[1]Rubbo (2023) shows this in a multisector model with a general input-output structure and the textbook Calvo friction. Woodford (2003), Aoki (2001), and Benigno (2004) show the same in models without the general network structure, as in the environment presented here, again under the Calvo friction.

ing only sector 1. The relative price of sector 1 should fall. In the menu cost world with optimal monetary policy, sector-1 firms pay a menu cost and cut nominal prices, while other sectors leave prices unchanged: relative prices are correct and only one sector pays the menu cost. In the Calvo model under the same monetary policy, some firms within sector 1 cut prices, but the rest of sector-1 firms are exogenously prevented from cutting prices. Thus, there is relative price dispersion within sector 1. In other sectors, prices are unchanged, and there is zero within-sector dispersion.

But optimal monetary policy under Calvo is different: instead, the central bank optimally *loosens* monetary policy. The loosening causes firms in unshocked sectors to want to raise their prices. Because some firms in these sectors are exogenously prevented from adjusting prices, this creates relative price dispersion in these unshocked sectors, whereas previously there was zero dispersion. Howevever, this new dispersion comes alongside a benefit: by actively loosening monetary policy, firms in the shocked sector 1 *do not want to cut their prices as deeply*, reducing the degree of dispersion within sector 1. Precisely because of the convexity of the welfare loss from price dispersion, this tradeoff is worthwhile. It is better to disrupt and create at least a little price dispersion in *every sector*, rather than to have a lot of price dispersion in one sector.

Quantitative model. We extend our results to a richer, dynamic model to study whether the results continue to hold and to quantify the welfare loss of inflation targeting. This model is estimated to match US data, with particular attention to salient moments related to firms' price-setting behavior. In addition to the sectoral shocks that are present in the baseline model, the quantitative model includes idiosyncratic, firm-level shocks and adopts the "CalvoPlus" framework of Nakamura and Steinsson (2010) in which occasionally firms get a chance to adjust prices at no cost.

We show that stabilizing nominal wages outperforms stabilizing inflation in this richer environment. Simulating an economy in which all sectors are subject to sectoral productivity shocks estimated to match the dynamics of output in the US from 1984 to 2019, we find that the welfare gain of moving from inflation to nominal wage targeting is 0.32% in consumption-equivalent terms. This improvement comes in part from higher menu cost expenditure under inflation targeting due to unnecessarily frequent price adjustment.

These results are related to the fact that the empirical literature estimates menu costs to be fairly large. Based on directly-measured costs alone, the existing literature finds that between 0.6% and 1.2% of firm revenue is spent per year on costs related to price adjustment (Levy et al. 1997; Dutta et al. 1999; Zbaracki et al. 2004).[2] We calibrate the

---

[2]The important measurement work of Levy et al. (1997), Dutta et al. (1999), and Zbaracki et al. (2004) is extensively cited in the menu cost literature. These measurements are, as we emphasize, endogenous to the

quantitative model to the findings of this literature.

Position in literature. To our knowledge, we are the first to fully characterize optimal monetary policy in the face of fixed menu costs when firms have a motive to adjust relative prices. On the one hand, without changes in productivity between firms, there is no motive for relative-price changes and so optimal policy under menu costs is simply zero inflation: prices never need to move and price stickiness is irrelevant (Nakov and Thomas 2014). On the other hand, several papers allow for relative-price movements under menu costs but take as given that the central bank targets inflation, and simulate numerically how the presence of menu costs affects the optimal level of inflation (Blanco 2021, Nakov and Thomas 2014, Wolman 2011).[3]

Of most relevance, Adam and Weber (2023) study optimal monetary policy at steady state under menu costs with deterministic productivity trends, to a first-order approximation, which is complementary to our study of optimal policy in response to stochastic productivity shocks. Adam and Weber (2023) explicitly turn off consideration of minimizing resource costs (their Assumption 1), which our analytical results highlight as an important factor in optimal policy. Contemporaneously, Karadi et al. (2025) quantitatively study optimal monetary policy under menu costs in a single-sector environment with idiosyncratic shocks. In that environment, like in our model and as discussed above, optimal policy in response to a productivity shock that is *perfectly* uniform across all firms is zero inflation. Relative to their other, computational analysis, our analytical results characterize and provide intuition for the specific economic forces driving optimal policy.

Our model formalizes and extends the insightful, literary argument made by Selgin (1997) (chapter 2, section 3) that nominal income targeting, or something like it, is optimal in a world with menu costs. Relative to Selgin's elegant informal discussion, we are able to introduce the role of state dependence, which is natural in the context of menu costs and does affect optimal policy. Additionally, we are able to formalize and be precise about the argument in the context of a standard macro model. This formalization allows us to characterize precisely the natural of optimal policy, to connect our results to prior modeling work, and to quantify the welfare costs of inflation targeting.

A larger literature makes assumptions on monetary policy – i.e. does not analyze optimal policy – and asks how the presence of menu costs affects macroeconomic dynamics.[4]

---

monetary policy regime.

[3]Away from menu costs, other papers that analyze optimal monetary policy in a sectoral setting, i.e. a setting with relative price movements, besides those already cited include the vertical chain model of Huang and Liu (2005), again under the Calvo friction; Kreamer (2022) as well as Erceg and Levin (2006), who study optimal monetary policy in sectoral models with fixed prices and durable goods; and Guerrieri et al. (2021), who study optimal monetary policy in a sectoral model with downward nominal wage rigidity.

[4]Among many others: Caplin and Spulber (1987); Golosov and Lucas (2007); Gertler and Leahy (2008);

There is also a large empirical literature on menu costs.[5]

The bigger picture.   We see our paper as helping unify the literature on optimal monetary policy. In the last decade a number of papers across a variety of classes of models have found that optimal policy should cause inflation to be countercyclical, not constant: the price level P should move inversely with real output Y. However, sticky price models – the workhorse model of modern macro – had conspicuously held out for the optimality of inflation targeting.

First, Koenig (2013) and Sheedy (2014) show in heterogeneous agent models that when financial markets are incomplete and debt is written in nominal, non-state contingent terms, then nominal income targeting is optimal and inflation targeting is suboptimal. That is, $P \times Y$ should be stabilized, and therefore P and Y should move inversely.[6] Second, Angeletos and La'O (2020) show that in a world where agents have incomplete information about the economy, optimal policy should again ensure the price level P and real output Y move inversely, in order to minimize monetary misperceptions.[7] Third, when wages are sticky due to a Calvo-type friction, optimal monetary policy is to stabilize nominal wages (Erceg, Henderson and Levin 2000), a policy which also results in countercyclical price inflation.

Despite these results in three highly important classes of models – incomplete markets, information frictions, and sticky wages – it may have been easy to set them aside and nonetheless consider inflation targeting as the proper baseline for optimal monetary policy due to its optimality in the workhorse sticky price model (e.g. Woodford 2003).[8] We hope our paper helps integrate these results from across the literature on incomplete market, information friction, sticky wages, and sticky prices. Our results suggest that *countercyclical inflation*, not stable inflation, is a robustly-optimal policy prescription.

Outline.   We first illustrate the optimal policy result in sections 2 and 3 in a baseline setting as described above: an off-the-shelf sectoral model, augmented with menu costs, hit by an unanticipated sectoral productivity shock. In section 4, we use our setup to

---

Nakamura and Steinsson (2010); Midrigan (2011); Alvarez, Lippi and Paciello (2011); Auclert et al. (2023). Guerreiro et al. (2024) study the positive implications of menu costs on wages.

[5] Among many others: Alvarez et al. (2019); Nakamura et al. (2018); Cavallo (2018); Cavallo and Rigobon (2016); Klenow and Kryvtsov (2008); Gautier and Le Bihan (2022).

[6] These ideas have been developed further in Bullard and DiCecio (2019) and Bullard et al. (2023). Werning (2014) also notes that if additional heterogeneity is added to the model, then P and Y should move inversely but not one-for-one. This echoes our results.

[7] The nominal contracts and incomplete information literatures also were preceded and discussed very clearly by Selgin (1997).

[8] In the textbook sticky price model, countercyclical inflation can be optimal if there is a binding zero lower bound constraint on the nominal interest rate (Eggertsson and Woodford 2003; Werning 2011; Woodford 2012).

shed new light on the conventional New Keynesian model. In section 5, we show that the optimality of nominal wage targeting continues to hold analytically under a number of generalizations. In section 6, we generalize further by building a quantitative model in order to incorporate dynamics and calculate the welfare gains of adopting nominal wage targeting. Section 7 concludes with a brief discussion of practical implementation.

2 Baseline model

Our baseline framework is a two-period model starting at steady state. There are S sectors, each consisting of a continuum of monopolistically competitive intermediate firms which are aggregated into a sectoral good by a competitive sectoral packager. A competitive final goods producer combines the output of each of the S sectors into a final good, sold to the household. The model and the functional forms we use are the same as Golosov and Lucas (2007), except that productivity shocks are sectoral rather than firm-specific and we analyze optimal monetary policy instead of exogenous monetary shocks. In section 5, we generalize the functional forms.

2.1 Household

The representative household's utility function is given by

$$\mathbb{W} = \ln C - N + \ln \left(\frac{M}{P} \right) \tag{1}$$

Utility is a function of consumption C, labor N, and real money holdings $\frac{M}{P}$.[9] The household chooses C, N and M to maximize its utility, subject to its budget constraint:

$$PC + M = WN + D + M_{-1} - T$$

To fund expenditures, the household uses labor income from wages W, firm dividends D, and previous period money balances M_{-1}, less taxes T. The first order conditions imply:

$$PC = M \tag{2}$$

$$W = M \tag{3}$$

---

[9]We follow Woodford (1998) in ignoring the welfare effects of real balances when analyzing optimal monetary policy. Additionally, we need not use a money-in-utility framework – the results generalize to any framework where the central bank controls some nominal variable – but it allows us to depart minimally from existing literature.

Our particularly simple assumptions on preferences – again matching those of Golosov and Lucas (2007) – result in two simple optimality conditions: an equation of exchange (2) and an equation (3) stating that in equilibrium the nominal wage W is directly determined by the money supply M.

2.2 Final good producer

The representative final good producer aggregates sectoral goods y_i of price p_i across S sectors, using Cobb-Douglas technology, into the final good Y consumed by the household. Operating under perfect competition, its problem is:

$$\max_{\{y_i\}_{i=1}^S} PY - \sum_{i=1}^S p_i y_i$$
$$\text{s.t. } Y = \prod_{i=1}^S y_i^{1/S} \tag{4}$$

The resulting demand for sectoral goods is:

$$y_i = \frac{1}{S} \frac{PY}{p_i} \tag{5}$$

The zero profit condition gives the price P for the final good:

$$P = S \prod_{i=1}^S p_i^{1/S} \tag{6}$$

In section 5.1 we discuss how generalizing the Cobb-Douglas functional form used here has no impact on the optimal policy result.

2.3 Sectoral goods producers

In sector i, a representative sectoral goods producer packages the continuum of intermediate goods, $y_i(j)$, produced within the sector using CES technology. Note that for notational clarity, we will consistently use j to identify an intermediate firm and i to identify a sector. The problem of the sectoral packager for sector i is:

$$\max_{[y_i(j)]_{j=0}^1} p_i y_i - \int_0^1 p_i(j) y_i(j) dj$$

7

$$\text{s.t. } y_i = \left[\int_0^1 y_i(j)^{\frac{\eta-1}{\eta}} \right]^{\frac{\eta}{\eta-1}} \tag{7}$$

This results in a demand function $y_i(j)$ and a sectoral price index p_i:

$$y_i(j) = y_i \left(\frac{p_i(j)}{p_i} \right)^{-\eta} \tag{8}$$

$$p_i = \left[\int_0^1 p_i(j)^{1-\eta} dj \right]^{\frac{1}{1-\eta}} \tag{9}$$

2.4   Intermediate goods producers

In each sector there is a unit mass of monopolistically competitive firms, each producing a different variety of the sectoral good. Their technology is linear, and all firms within a sector i share a common productivity level A_i.[10] The linearity of technology significantly simplifies the exposition and is important for generating the optimality of nominal wage targeting; we generalize this in section 5.

Intermediate firms are subject to menu costs: if they choose to adjust their price, they must hire an extra ψ units of labor at the wage rate W. This fixed cost of price adjustment, $W\psi$, is what we refer to as a "menu cost". The menu cost itself is simply a transfer from firm profits to household labor income; the *welfare cost* of menu costs comes from the fact that households must supply extra labor in order for prices to be adjusted, and there is a disutility cost associated to this additional labor. This is motivated by the idea of firms needing to employ workers for extra hours to physically walk around and update price stickers in a store, but more generally can be thought of as a modeling device to stand in for *any* fixed costs of price adjustment. For example, if menu costs are optimization costs, $W\psi$ represents the opportunity cost of the labor time spent thinking about what the optimal price adjustment should be. Modeling menu costs in other ways does not affect the optimal policy conclusions.[11]

---

[10]Note that it is standard in the optimal policy literature on sectors and networks to only consider the optimal policy response to *sector*-level productivity shocks: see for example Rubbo (2023), Woodford (2003), Aoki (2001), or Benigno (2004). In particular, these papers do not consider idiosyncratic, firm-level productivity differences. In contrast, in the separate literature on menu costs, it is common to consider such idiosyncratic shocks (Golosov and Lucas 2007; Karadi et al. 2025). We analyze the case of both sectoral and idiosyncratic shocks using the quantitative model in section 6.

[11] One example of an alternate modeling method is when menu costs burn real resources (as in Alvarez, Lippi and Paciello 2011), and therefore lower the level of profits transferred to households. Another, more behavioral, modeling method would be to model menu costs as directly inflicting a utility penalty on households, as in Auclert, Rognlie and Straub (2018) and as could be motivated by the literature on fairness in pricing (e.g. Eyster, Madarász and Michaillat 2021). It is straightforward to show that optimal policy is the same if menu costs are modeled in either of these ways, as we show in the behavioral case in appendix B.

Firm j in sector i thus maximizes profits, including the menu cost if choosing to adjust its price, subject to its demand curve and its production technology, taking as given the inherited price from the previous period $p_i^{\text{old}}(j)$:

$$\max_{p_i(j)} p_i(j)y_i(j) - Wn_i(j)(1-\tau) - W\psi\chi_i(j)$$

$$\text{s.t. } \chi_i(j) = \begin{cases} 1 & \text{if } p_i(j) \neq p_i^{\text{old}}(j) \\ 0 & \text{else} \end{cases}$$

$$y_i(j) = y_i \left(\frac{p_i(j)}{p_i} \right)^{-\eta}$$

$$y_i(j) = A_i n_i(j) \tag{10}$$

The objective function defines firm profits, $D_i(j)$. The variable $\chi_i(j) \in \{0,1\}$ is a dummy indicating whether or not the firm chooses to adjust its price, $p_i(j)$. If it does, it incurs the menu cost $W\psi$. Otherwise, the price remains at the level inherited from the previous period, denoted $p_i^{\text{old}}(j)$. The term τ in the firm's problem is the standard labor subsidy provided by the fiscal authority to undo the markup distortion from monopolistic competition, $\tau = \frac{1}{\eta}$, for each unit of labor used in production, $n_i(j)$.

If the firm chooses to pay the menu cost and adjust its price, then – from the firm's first order condition – the optimal reset price equals the nominal marginal cost:

$$p_i(j) = \frac{W}{A_i} \tag{11}$$

Notice that, because productivity is sector-specific, all firms j within a sector i face the same decision problem, and thus all make the same decision on whether to adjust and choose the same reset price. Because of this equivalence, we will often refer interchangeably to firm-specific versus sector-specific prices and quantities, e.g. $p_i(j)$ versus p_i and $n_i(j)$ versus n_i.[12]

2.5 The intermediate firm's adjustment decision

We now turn to the question of whether a given intermediate firm will pay the menu cost to adjust its price. The firm makes its decision to adjust by comparing profits under the new optimal price $\frac{W}{A_i}$ net of the menu cost $W\psi$, versus profits under the inherited price p_i^{old} without the loss from menu costs. Plugging in the respective prices as well as

---

[12]Where sectoral labor is defined naturally as $n_i \equiv \int_0^1 n_i(j)dj$.

9

constraints into the profit function, we arrive at the price-adjustment condition: firm j in sector i will adjust if and only if

$$\left(\frac{W}{A_i}\right)^{1-\eta} p_i^\eta y_i \left[\frac{1}{\eta}\right] - W\psi > \left(p_i^{\text{old}}(j)\right)^{1-\eta} p_i^\eta y_i \left[1 - \frac{W/A_i}{p_i^{\text{old}}(j)} \cdot \frac{\eta-1}{\eta}\right] \tag{12}$$

This nonlinear adjustment condition implies an inaction region Λ, a standard result in menu cost models. The following lemma describes the inaction region.

Lemma 1 (Inaction region). There exists an inaction region Λ in (W, A_i) space such that a firm in sector i will not adjust its price if and only if the value of (W, A_i) remains within this inaction region:

$$(W, A_i) \in \Lambda \tag{13}$$

The larger the menu cost ψ, the larger is this inaction region. The locus of points that result in the new optimal price equaling the inherited price, $\{(W, A_i)|\frac{W}{A_i} = p_i^{\text{old}}\}$, always lies within the inaction region. The inaction region is a connected set.

Proof: See Appendix A.1. □

To interpret this, note that the desired reset price W/A_i depends on two factors:

1. The sectoral productivity A_i, which is exogenous.

2. The level of nominal wages W, which we saw from (3) is completely determined by the central bank, $W = M$, in equilibrium.

Thus, firms are more likely to adjust after either a large productivity shock or a large monetary action, all else equal.

2.6   Market clearing

Labor market clearing implies that total labor supplied by the household, N, equals labor demanded in production, $\sum_i n_i$, plus the amount of labor required to adjust prices, which is $\psi \sum_i \chi_i$:

$$N = \sum_{i=1}^{S} n_i + \psi \sum_{i=1}^{S} \chi_i \tag{14}$$

This market clearing condition is key to the welfare costs of menu costs. Since labor supply N enters the household utility function negatively, larger menu costs ψ requiring

the household to work more to adjust prices will lower household welfare.

The remaining equilibrium conditions are standard. The government budget constraint is: $T + (M - M_{-1}) = \tau W \sum_{i=1}^{S} n_i$. Finally, the aggregate resource constraint implies that consumption equals aggregate output:

$$C = Y \tag{15}$$

2.7 Steady state

The economy begins in a symmetric, flexible-price steady state (steady state variables are denoted with a superscript *ss*) in which sectoral productivities A_i^{ss} for $i \in \{1, \ldots, S\}$ are taken as given and the money supply is normalized to $M^{ss} = 1$. Without loss of generality, we can set $A_i^{ss} = 1$ for all i.

Nominal wages from (3) are then $W^{ss} = 1$. Firms set prices at their flexible levels (11), $p_i^{ss} = 1$. The aggregate price level (6) is $P^{ss} = S$. From money demand (2), consumption and therefore output are equal to aggregate productivity, $C^{ss} = Y^{ss} = M^{ss}/P^{ss} = 1/S$. From demand equations (8) and (5), sectoral output is $y_i^{ss} = \frac{1}{S}$. From intermediate production technology (10) we recover labor in sector i as $n_i^{ss} = \frac{1}{S}$ and aggregate labor from market clearing (14) as $N^{ss} = 1$.

3   Optimal policy after a productivity shock

As our baseline exercise, we consider the optimal response to an unexpected shock to sector 1 alone. For concreteness, consider a positive productivity shock, which we denote as $\gamma > A_1^{ss} = 1$. How should monetary policy optimally set the money supply M?

Because in the initial steady state all sectors have the same productivity normalized to one, firms in all unshocked sectors $i > 1$ face precisely the same problem after the shock to sector 1 and make the same decision on whether and how to adjust. As a result, for our purposes in this section there are effectively two sectors of different sizes, sector 1 (with productivity $A_1 = \gamma > 1$ and size 1) and sectors k (with productivity $A_k = 1$ and size $S - 1$). Section 5.3 discusses how this generalizes to shocking multiple sectors. We will consistently identify variables for these unshocked sectors with a k. The relative price between the shocked and unshocked sectors, p_1/p_k, will be a key object of analysis.

Proposition 1, our benchmark result, characterizes optimal monetary policy in response to this shock.

Proposition 1 (Optimal monetary policy)**.** For a fixed level of menu costs ψ, there exists a

threshold level of productivity $\overline{\gamma} > 1$, such that:

1. If the productivity shock to sector 1 is above the threshold, $\gamma \geq \overline{\gamma}$, then optimal policy is exactly nominal wage targeting: monetary policy should ensure $W = W^{ss}$. This results in firms in sector 1 adjusting their prices, while firms in other sectors k leave prices unchanged. This is implemented by leaving the money supply unchanged, $M = M^{ss}$.

2. If the shock is below the threshold, $\gamma \in [1, \overline{\gamma})$, then optimal policy is to ensure that prices remain unchanged and no firm in any sector adjusts.

Additionally, the productivity threshold $\overline{\gamma}$ is increasing in the size of menu costs ψ.

Proof: Lemma 2 and lemma 3 below directly imply the proposition. □

First, we review the economic intuition, which was previewed in the introduction, before proving the proposition. For a sufficiently large productivity shock $\gamma \geq \overline{\gamma}$, it is efficient for the relative price of sector 1, p_1 / p_k, to update. To achieve this while simultaneously minimizing the number of sectors which must incur a wasteful menu cost, it is only necessary that firms in sector 1 update their price p_1 – firms in other sectors do not need to update p_k. To ensure that firms in other sectors have no desire to update, the central bank wants to stabilize the level of nominal wages, W, so that the nominal marginal cost of firms in these other sectors is unchanged and these firms have no motive to adjust their prices. On the other hand, for a small productivity shock $\gamma \in [1, \overline{\gamma})$, the benefit of updating the relative price p_1 / p_k does not outweigh the welfare loss from the menu cost necessary to do so. It is therefore optimal to ensure that prices remain unchanged across all sectors.

We next step through the math behind this intuition in more detail. We build up to lemma 2 and lemma 3, which together prove proposition 1.

3.1 Allocations in four possible regimes

In this subsection, we characterize the four possibilities for equilibrium that monetary policy can implement. In the next subsection, we will compare welfare across them.

Because, applying symmetry, there are two types of firms (those in sector 1 hit with productivity shock γ, and those in other sectors k with unchanged productivity) and each type has a binary choice (adjusting or not adjusting its price), there are 2×2 possibilities for what may occur in equilibrium:

1. Both sector 1 and sectors k adjust prices

2. Only sector 1 adjusts its price; sectors k do not adjust

3. Only sectors k adjusts their prices; sector 1 does not adjust

4. Neither sector 1 nor sectors k adjusts price

The central bank determines which of these regimes occurs in equilibrium by manipulating the money supply, M. Whether a firm in some sector i decides to adjust its price depends solely on whether its target price, $\frac{W}{A_i}$, is outside its inaction region (13). Because the central bank can move nominal wages W by its choice of money supply M, it controls which equilibrium is implemented. (Note that there is always a unique equilibrium for a given choice of M – this is not a choice of *equilibrium* selection, but a choice by monetary policy of how much to increase aggregate demand.)

The optimal policy problem thus consists of:

1. Considering each of these regimes individually, and choosing M to maximize welfare *conditional* on the given regime;

2. Then, choosing the regime among the four which has the highest welfare, and implementing the associated optimal M.

This optimal policy problem, formalized in (61) in appendix A.2, is necessarily piecewise due to the sharp discontinuities created by the discontinuous pricing rules of (13), themselves the result of the fixed menu costs.

We now consider each of these four regimes individually, after discussing a benchmark of flexible prices. The ensuing subsection compares across the four.

Flexible price benchmark. As a benchmark, first consider the flexible price allocation, where the menu cost $\psi = 0$. Nominal wages are determined by the money supply, $W = M$, so that from (11) the flexibly-adjusted prices are $p_1 = \frac{M}{\gamma}$ and $p_k = M$. Observe that under flexibility, the relative price across types $\frac{p_1}{p_k}$ is:

$$\left(\frac{p_1}{p_k} \right)_{\text{flex}} = \frac{1}{\gamma}$$

This is an important object. This flexible relative price results in aggregate output and consumption equal to $Y = C = \frac{\gamma^{1/S}}{S}$. Total labor, as in steady state, is $N = 1$. Plugging these quantities into the household utility function (1), we have a flexible-price benchmark for welfare of:

$$\mathbb{W}_{\text{flex}} = \ln \left(\frac{\gamma^{1/S}}{S} \right) - 1 \tag{16}$$

13

The flexible-price level of welfare is the first-best, efficient benchmark to which policy should be compared.

All sectors adjust. Next, return to the world where there are nonzero menu costs, and consider the case where all sectors pay the menu cost to adjust. Because all firms adjust to the flexible levels of $p_1 = \frac{M}{\gamma}$ and $p_k = M$, the relative price achieves the flexible price level:

$$\left(\frac{p_1}{p_k} \right)_{\text{all adjust}} = \frac{1}{\gamma} = \left(\frac{p_1}{p_k} \right)_{\text{flex}}$$

However, despite prices adjusting, the equilibrium differs from the flexible-price equilibrium because additional labor is required to pay the menu costs of price adjustment. This is where the assumptions on preferences plays a useful simplifying role: the fact that the Golosov-Lucas preferences are quasilinear in labor ensure that all income effects affect labor supply. As a result, the additional labor required for menu costs has no effect on equilibrium *except* to increase the amount of labor used.[13] That is, prices and quantities are the same as the flexible price equilibrium, *except* for the additional labor which must be hired to pay for the menu costs: $N = 1 + S\psi$, where $S\psi$ reflects that there are S sectors which must hire ψ units of labor each to adjust prices.

All together, this means that – conditional on all sectors adjusting – welfare is independent of monetary policy and it is equal to the flexible-price level minus the S sectors' worth of menu costs:

$$\mathbb{W}_{\text{all adjust}} = \ln \left(\frac{\gamma^{1/S}}{S} \right) - [1 + S\psi]$$

$$= \mathbb{W}_{\text{flex}} - S\psi \tag{17}$$

Only sector 1 adjusts. Next consider if only sector 1 updates to $p_1 = \frac{M}{\gamma}$ and sectors k leave their prices unchanged at the steady state level of $p_k = 1$. This results in aggregate output of $Y = \frac{\gamma^{1/S}}{S} M^{\frac{S-1}{S}}$. The total level of labor is $N = \left[\frac{1}{S} + (S-1)\frac{M}{S} \right] + \psi$, reflecting one sector's worth of menu costs ψ, since only sector 1 is adjusting. Thus, household

---

[13]Without preferences ensuring no income effects on consumption, optimal policy would need to account for the fact that the labor required for menu costs affects the marginal rate of substitution between consumption and leisure. Under optimal policy, production would therefore be slightly tilted away from the flexible-price level. An alternative approach would be to model menu costs as a utility penalty affecting the household directly (c.f. Auclert, Rognlie and Straub 2018 among others), in which case the flexible-price allocation is replicated exactly; we model this in appendix B. In general, as long as the income effects of menu costs are quantitatively small, then preferences which are quasilinear in labor are a good benchmark.

welfare is a function of the money supply decision:

$$W_{\text{only 1 adjusts}}(M) = \ln\left(\frac{\gamma^{\frac{1}{S}}}{S}M^{\frac{S-1}{S}}\right) - \left[\frac{1}{S} + (S-1)\frac{M}{S} + \psi\right]$$

Conditional on being in this regime, optimal monetary policy chooses M to maximize this expression, which can be found from the first order condition to be:

$$M^*_{\text{only 1 adjusts}} = 1$$

where asterisks denote objects under optimal policy.[14] The optimal money supply in this case is left unchanged at the steady state level, $M^{ss} = 1$. Importantly, this ensures that the relative price across sectors, $\frac{p_1}{p_k} = \frac{M}{\gamma}$, equals the flex-price level:

$$\left(\frac{p_1}{p_k}\right)^*_{\text{only 1 adjusts}} = \frac{1}{\gamma} = \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

Why does this policy result in the efficient relative price? Setting $M = 1$ ensures nominal wages are $W = 1$, since $M = W$ from (3), which means that nominal wages are unchanged from steady state $W^{ss} = 1$. As a result, the optimal reset price $\frac{W}{A_k} = W$ *coincides with* the inherited price, $p_k^{ss} = 1$, and the optimal pricing is achieved without a need to adjust.

Thus, optimal monetary policy is able to replicate the flexible-price allocation by ensuring that all prices are at the correct level despite sectors k not adjusting, aside from the extra labor required for menu costs. As a result, welfare under optimal policy is equal to the flexible-price level, minus one sector's worth of menu costs from sector 1 adjusting:

$$W^*_{\text{only 1 adjusts}} = \ln\left(\frac{\gamma^{1/S}}{S}\right) - [1 + \psi]$$

$$= W_{\text{flex}} - \psi \tag{18}$$

Only sectors k adjust. If only sectors $k = 2, ..., S$ adjust, the logic is similar to the prior case, except $S - 1$ sectors adjust, instead of only one sector adjusting. The flexible-price allocation is again achievable aside from the extra labor required to pay for menu costs, this time by ensuring that the desired price in sector 1 equals the inherited price. This is implemented by the central bank increasing the money supply, inflating nominal wages to the point where firms in sector 1 have no desire to adjust, $W = \gamma$, and causing firms

---

[14]In subsection 3.3, we discuss the incentive compatibility of this choice of money supply: i.e. if this choice of M ensures only sector 1 wants to adjust.

in other sectors to have a motive to adjust. The optimized level of welfare is thus the flexible-price level minus $S - 1$ sectors' worth of menu costs:

$$\mathbb{W}^*_{\text{only } k \text{ adjust}} = \mathbb{W}_{\text{flex}} - (S - 1)\psi \tag{19}$$

No sector adjusts. Finally consider the possibility that no firm in any sector adjusts. Sectoral prices are thus unchanged from steady state, $p_i = p_i^{ss} = 1 \ \ \forall i$, and consequently so is the aggregate price level, $P = P^{ss} = S$. Within this regime, this is as if all prices were fully rigid: aggregate output is determined by monetary policy, $Y = C = \frac{M}{S}$. Total labor is $N = \frac{1}{\gamma}\frac{M}{S} + (S - 1)\frac{M}{S}$, noting no labor is required for menu costs because no prices are adjusted. Household welfare as a function of the chosen level of the money supply M is:

$$\mathbb{W}_{\text{none adjust}}(M) = \ln\left(\frac{M}{S}\right) - \left[\frac{1}{\gamma}\frac{M}{S} + (S - 1)\frac{M}{S}\right]$$

Conditional on being in this regime, optimal monetary policy chooses M to maximize this expression, which can be found from the first order condition to be $M^*_{\text{none adjust}} = \left[\frac{1}{\gamma}\frac{1}{S} + \frac{S-1}{S}\right]^{-1}$. Under this, the optimized level of welfare is:

$$\mathbb{W}^*_{\text{none adjust}} = -\ln\left(S - 1 + \frac{1}{\gamma}\right) - 1 \tag{20}$$

To understand this, note that the relative price $\frac{p_1}{p_k}$ is stuck at the steady state value of 1 instead of being updated to the flexible price value of $\frac{1}{\gamma}$:

$$\left(\frac{p_1}{p_k}\right)_{\text{none adjust}} = 1 \neq \left(\frac{p_1}{p_k}\right)_{\text{flex}}$$

It is because this relative price is stuck at a distorted level that monetary policy is unable to achieve the flexible-price allocation.

3.2 Comparing across regimes

In this subsection, we compare welfare across the four possible regimes just derived. We can immediately observe that only two of the four are worth considering for optimal policy.

Lemma 2 (If adjusting, only the shocked sector should adjust)**.** Welfare when only sector 1 adjusts, $\mathbb{W}^*_{\text{only 1 adjusts}}$, is strictly higher than welfare when all sectors adjust, $\mathbb{W}^*_{\text{all adjust}}$,

16

and welfare when only sectors k adjust, $\mathbb{W}^*_{\text{only } k \text{ adjust}}$.

Proof: This follows immediately from comparing (18) with (17) and (19). □

Lemma 2 follows from the idea that it is better to have fewer firms incur menu costs, together with the fact that optimal policy can implement the efficient relative price $\left(\frac{p_1}{p_k}\right)_{\text{flex}}$ by having *either* sector 1 only adjust, *or* sectors k only adjust, *or* all sectors adjust. Thus, if any firms at all are going to adjust, it is best to have sector-1 firms only adjust.

What remains is to compare welfare if "only sector 1 adjusts" versus if "none adjust". The next lemma compares these two.

Lemma 3 (Only adjust prices beyond a threshold). There is a threshold $\overline{\gamma}$ such that $\mathbb{W}^*_{\text{only } 1 \text{ adjusts}}$ dominates $\mathbb{W}^*_{\text{none adjust}}$ if and only if the productivity shock exceeds the threshold, $\gamma \geq \overline{\gamma}$. Furthermore, the threshold $\overline{\gamma}$ is increasing in the menu cost ψ.

Proof: Define $f(\gamma) \equiv \mathbb{W}^*_{\text{none adjust}} - \mathbb{W}^*_{\text{only } 1 \text{ adjusts}}$. Observe that if $\gamma = 1$, then $f(\gamma) = \psi > 0$. Additionally, as $\gamma \to \infty$, then $f(\gamma) \to -\infty$. Finally, f is strictly monotonically decreasing in γ, with $f'(\gamma) = \frac{1}{\gamma}\left[\frac{1}{\gamma(S-1)+1} - \frac{1}{S}\right] < 0$. Since f is continuous in γ, by the intermediate value theorem there exists a $\overline{\gamma} > 1$ such that $f(\overline{\gamma}) = 0$. To see that $\overline{\gamma}$ is increasing in ψ, observe that increasing ψ shifts the entire $f(\gamma)$ curve up, i.e. $\frac{\partial f}{\partial \psi} > 0$. □

Lemma 3 says that there is an important threshold level $\overline{\gamma}$ for the productivity shock. Below this threshold, household welfare is maximized by ensuring that no firm in any sector adjusts; above this threshold, it is maximized by ensuring that sector-1 firms adjust. The intuition for this, as emphasized, is that the welfare loss from menu costs is fixed in size. For a sufficiently small improvement in productivity, the benefit to adjusting prices does not outweigh the fixed welfare loss from the menu cost that is required to adjust. It is only worthwhile to pay this fixed cost above the threshold. The proof follows this same logic.

Additionally, the productivity threshold $\overline{\gamma}$ is increasing in the size of the menu cost ψ. The intuition for this is that for a larger menu cost, the productivity shock must be bigger for it to be worthwhile to adjust.

In the case where none adjust, the level of nominal wages is $W_{\text{none adjust}} = M^*_{\text{none adjust}} = \left[\frac{1}{\gamma}\frac{1}{S} + \frac{S-1}{S}\right]^{-1}$. Observe that for $\gamma = 1$, then nominal wages are exactly unchanged from the steady state level of $W^{ss} = 1$. For small shocks, $1 < \gamma < \overline{\gamma}$, nominal wages are also approximately unchanged.

Denote welfare under optimal policy as $\mathbb{W}^*$, where lemma 2 and lemma 3 together imply $\mathbb{W}^* = \max\left\{\mathbb{W}^*_{\text{only } 1 \text{ adjusts}}, \mathbb{W}^*_{\text{neither adjust}}\right\}$. Lemma 2 and lemma 3 together also prove proposition 1.

3.3 Adjustment externalities

When discussing the regime where only sector 1 adjusts, we derived equilibrium household welfare as a function of the money supply choice, $W_{\text{only 1 adjusts}}(M)$, by *assuming* that only firms in sector 1 adjusted prices. We then found the optimal $M^*_{\text{only 1 adjusts}}$ by simply taking the first order condition of this function.

More precisely, however, a central bank would choose the money supply M that maximizes welfare $W_{\text{only 1 adjusts}}(M)$ *subject to the implementability constraint* that such a choice of M *induces* sector 1 to adjust and other sectors k not to adjust. We term this as "constrained" optimal. The choice of M would need to be incentive-compatible with the assumption on who is adjusting price. The same is true for the case where none adjust: the choice of optimal M must not push any firm outside its inaction region. (The same is true of the case where only sectors k adjust, though this is less important because of lemma 2.) These constraints can be written formally as in equations (54)-(56) in appendix A.2.

In proposition 1 and throughout the body of this paper, we have endowed the social planner with the power to force firms to adjust prices – or equivalently, to subsidize price adjustment – so that these implementability constraints are always nonbinding. This is written out explicitly in (58)-(60) in appendix A.2. In appendix B, however, we show that if the planner does not have this instrument, then it is possible for these implementability constraints to bind.

We term the case where the unconstrained-optimal choice of M is not feasible as "adjustment externalities", and discuss these in detail in appendix B. It may be the case that it is socially optimal for firms in sector 1 to adjust their prices, but it may not be privately optimal to adjust: prices are "too sticky", and there is a positive externality to price adjustment. It is also possible, however, that it is socially optimal for firms in either sector 1 or in sectors k to leave their price unchanged, but it is privately optimal to adjust: prices are "too flexible", and there is a negative externality to price adjustment. The nature of the externality depends on the size of the shock and the size of menu costs, as detailed in appendix B. For the purposes of proposition 1 and for our other analytical results, we have endowed the planner with the choice to overcome adjustment externalities by selectively subsidizing price adjustment.

This issue does not arise in the Calvo literature since there is no cost of adjusting prices (when adjustment is possible). Therefore, these adjustment externalities do not arise. As a result, there is limited precedent in the literature, with a handful of important exceptions. Ball and Romer (1989a) find that menu costs create negative externalities after a *monetary policy shock*. Our setting instead studies whether *efficient* (productivity) shocks create externalities when monetary policy is set optimally and finds the possibility of

not just negative externalities but also the possibility of positive adjustment externalities. Other related studies include Ball ([1987](#)) on negative externalities in the length of labor contracts; Ball and Romer ([1989*b*](#)) on externalities in the timing of staggered price setting; and Ball and Romer ([1991](#)) on the possibility of menu cost-induced multiple equilibria. All of these papers study economies where monetary policy is not set optimally; our results show that, *even* when monetary policy is set optimally, adjustment externalities may arise.

Finally, Angeletos and La'O ([2020](#)) study optimal monetary policy under information frictions, and in the case of endogenous information acquisition studied in their online appendix A, they find that there are no externalities to information acquisition in price-setting if technology is specified as Dixit-Stiglitz as long as monetary policy is set optimally.[15] In our setting with optimal policy under menu costs, rather than information frictions, we show the possibility of externalities even under the Dixit-Stiglitz specification.

3.4 Discussion: "Menu costs" in the model can be interpreted broadly

The term "menu costs" originates with the *physical* resource costs of updating posted prices: restaurants needing to print new menus, or retailers needing to pay workers to replace price stickers on their shelves. These physical resource costs are sizeable and underappreciated; we review the literature in section [4.2](#), where direct measurement shows these to be between 0.6% and 1.2% of firm revenues in key industries of the economy.

However, menu costs can be conceptualized more broadly than simply physical resource costs, both in reality and through the lens of our model. Consider four possible sources of menu costs:

1. **Physical adjustment costs.** This is the baseline interpretation of our model and proposition [1](#). For example, retail firms needing to pay to print new price stickers and employ workers in updating these stickers on store shelves.

2. **Optimization costs.** "Menu costs" may represent fixed costs of *optimization* or *information processing*. Suppose firm managers have full information but must invest time thinking about what price to set. These costs operate through the same mechanism as in the model above: these costs require more labor. Optimal policy in this environment is unchanged: monetary policy should minimize unnecessary price adjustments, to reduce resources expended on information processing.

---

[15]Gorodnichenko ([2008](#)) studies a model with both menu costs and information frictions and numerically studies an information externality that results from their interaction. Caplin and Leahy ([2010](#)) also speculate informally about such a phenomenon; see also Caplin and Leahy ([1994](#)).

3. **Behavioral costs.** "Menu costs" could, alternatively, be interpreted more behaviorally: perhaps consumers have an intrinsic *preference* for stable prices, and changing prices has a direct psychological cost on consumers. In appendix B, we model menu costs as directly impinging on household welfare. Optimal policy is unchanged, since the core intuition of proposition 1 carries through: monetary policy should minimize unnecessary price adjustments, to reduce psychological costs caused by price adjustment.[16]

4. **Zero-sum backlash.** Optimal policy would be altered if "menu costs" are zero sum. Suppose "menu costs" in the firm's problem simply represent a behavioral *backlash* by consumers to changes in prices: in response to a change in prices, consumers shift their purchases from one firm to another. In this case, there need not be *aggregate* consequences of "menu costs", since one firm's loss may be another's gain. Note that taking this seriously as the *only* reason for menu costs would entail strong and unlikely conclusions: optimal policy would be to hyperinflate every period, to ensure that firms are induced to adjust, so that relative prices are always correct – without any cost. However, if menu costs are at all non-zero, then the optimal policy results here go through.

The general principle is that any fixed cost of price adjustment which is not zero sum operates through the same logic as proposition 1. In reality, "menu costs" likely are a combination of both zero-sum and non-zero-sum costs. To the extent that menu costs at all have a non-zero-sum component, the logic of proposition 1 goes through.

4   The welfare loss of inflation targeting & comparison with the Calvo model

In this section, we contrast our optimal policy results under menu costs to those of the canonical sticky price New Keynesian model, where prices are sticky exogenously due to the Calvo assumption.[17]

---

[16]If these psychological costs are asymmetric and consumers only react negatively to price increases, then optimal policy would be altered. In response to a positive productivity shock, nominal wage targeting would remain optimal. In response to a negative productivity shock, optimal policy would stabilize the nominal marginal costs of the adversely affected sectors.

It is not clear whether consumers have an asymmetric distaste for price increases. Anderson and Simester (2010) conduct a field experiment with a publisher and find that customers are significantly antagonized by price *decreases*.

[17]Throughout the paper, we refer to "Calvo" sticky pricing, for the sake of space and following the vast majority of the literature. A fuller accounting would refer to the "Calvo-Yun assumption", in reference to

1. We first discuss how stabilizing inflation under menu costs generates a welfare loss, in contrast to the standard Calvo model where stabilizing inflation is optimal. This is also directly policy-relevant, because leading central banks today describe their policy goals in terms of inflation targeting. This welfare loss is determined by the size of menu costs.

2. Second, we review the direct estimates available in the empirical literature on the size of *physical* menu costs. They are large: at least 0.5% of firm revenue and plausibly much more.

3. Third, we contrast optimal policy in our setting of *nonconvex* menu costs with optimal policy in a model of quadratic *convex* menu costs (Rotemberg 1982). In the convex setting, inflation targeting is optimal, like the Calvo model.

4. Finally, we use the preceding discussion to explain why the standard Calvo model prescribes inflation targeting and not nominal wage targeting, in contrast to the model we present here, shedding new light on the canonical model.

4.1 The welfare loss of inflation targeting under menu costs

The standard New Keynesian model of sticky prices, built on the Calvo exogenous sticky pricing framework, implies that a policy of zero inflation is optimal policy; but in our menu cost setting, such inflation targeting would be strictly suboptimal. This subsection shows a simple result characterizing, quantitatively, the extent of the welfare loss associated with inflation targeting.

In order to implement inflation targeting – i.e. in order to ensure that the price level is unchanged with $P = P^{ss} = 1$ – the central bank has two possibilities:

1. "All adjust": It may force all firms to adjust, and set M to ensure that the increase in price in sectors k to $p_k = M$ exactly offsets the fall in price in sector 1 to $p_1 = M/\gamma$.

2. "None adjust": It may ensure that no firm in any sector adjusts.

Although per proposition 1 it is optimal to ensure no sector adjusts in the case of small productivity shocks, $\gamma < \overline{\gamma}$, it would be unusual to conceptualize a policy of inflation targeting as aiming for a world in which relative prices *never* change. If maintained indefinitely, such a policy of aiming to prevent all relative price changes would seem to be self-evidently unreasonable, since it would shut down the price system. Thus it is more natural to characterize "inflation targeting" in this context as referring to the policy that would ensure all firms adjust.

---

the important work of Yun (1996).

Thus, inflation targeting requires all firms to adjust – but we saw above that forcing all sectors to adjust prices results in unnecessary menu costs. Thus, the welfare loss of inflation targeting relative to optimal policy is directly captured by the welfare loss caused by the unnecessary menu costs paid by the $S - 1$ unshocked sectors. The empirical size of menu costs ψ together with the number of unshocked sectors $S - 1$ are sufficient statistics for the welfare gains that would come from moving from inflation targeting to nominal wage targeting.

The next proposition summarizes this discussion.

Proposition 2 (The welfare loss of inflation targeting). Denote a policy of "inflation targeting" as a rule for monetary policy ensuring that $P = P^{ss}$ while having correct relative prices, and suppose $\gamma \geq \overline{\gamma}$. Then:

1. Inflation targeting requires that all sectors adjust their prices. It is implemented by increasing the money supply to $M = \gamma^{1/S} > M^{ss}$.

2. Welfare under inflation targeting, denoted $\mathbb{W}^{IT}$, is strictly less than welfare under the optimal policy described in proposition 1, $\mathbb{W}^*$. The welfare loss is determined by size of menu costs ψ and the number of sectors unaffected by the shock, $S - 1$:

$$\mathbb{W}^{IT} - \mathbb{W}^* = (S - 1)\psi$$

Proof: The second claim comes from formulas (17) and (18). For the first claim, suppose the central bank tried to both achieve correct relative prices by only having sector 1 adjust – in which case, $P = SM^{1/S}\gamma^{-1/S}$ – and simultaneously setting M such that the price level was unchanged, $P = P^{ss} = S$. This would require $M = \gamma$. However, if $M = \gamma$ then the optimal price for firms in sector 1 is $p_1 = W/\gamma = 1$, which would mean that firms in sector 1 leave prices unchanged, a contradiction. Similarly, if the central bank tried to achieve correct relative prices while only having sectors k adjust, in which case $P = SM^{\frac{S-1}{S}}$, then this would require $M = 1$, which would cause firms in sectors k to not adjust, again a contradiction. Finally, if no sector adjusts, then it is impossible to achieve correct relative prices, since $p_1/p_k = 1$. It is only by having firms in all sectors adjust, in which case $P = SM\gamma^{-1/S}$, that the central bank can achieve both correct relative prices and ensure that $P = P^{ss}$, by setting $M = \gamma^{1/S}$. $\square$

4.2 Empirical estimates of the size of menu costs are sizeable

In this subsection, we review the literature measuring menu costs.

A reaction to proposition 2 may be the idea that the welfare costs imposed directly from updating prices could be relatively small. The literature on menu costs often builds on the idea that 'second-order menu costs can result in first-order output fluctuations' (Mankiw 1985), in which case the welfare loss of inflation targeting compared to optimal policy would be second-order.

However, it is important to note that in the textbook New Keynesian model with the exogenous Calvo friction, the welfare loss of price stickiness is *also* only second-order (see e.g. Gali 2008).

Additionally, estimates of the real resource cost of menu costs from the empirical literature in fact are quite sizeable and arguably underappreciated: at least 0.5% of total firm revenues annually. These estimates come from two sources: calibrated models and direct measurement.

Calibrated models. One method for estimating the size of menu costs is to measure the frequency of price adjustment, build a model of price adjustment with menu costs, and calibrate the magnitude of menu costs to fit the microdata on the frequency of price adjustment. A number of papers perform this exercise, such as Nakamura and Steinsson (2010), who estimate the size of menu costs to be around 0.5% of revenue per year (their Table II).

Direct measurement. A more direct and model-free approach to measuring menu costs is to simply measure them directly. However, because measuring all forms of menu costs – physical adjustment costs, optimization costs, psychological costs – is difficult, the extant measurement literature focuses on physical adjustment costs alone. These numbers therefore can be interpreted as a lower bound on the total size of "menu costs" for the relevant firms.

To our knowledge, only three papers directly measure menu costs. Levy et al. (1997) directly measures the physical costs of price adjustment for five large grocery store chains across the US. They directly measure the time spent by workers manually changing price stickers on grocery store shelves, using a stopwatch. Such time maps directly the menu cost parameter ψ in our model. They find such menu costs to be 0.7% of firm revenue on average. Dutta et al. (1999) use a similar approach to examine a large drugstore chain, with a narrower conception of menu costs, and find menu costs to be 0.6% of firm revenue. Finally, Zbaracki et al. (2004) examine an industrial manufacturer and, using a broader conception of menu costs, find such costs to be 1.2% of firm revenue.[18]

---

[18]Of course, any measurement of the level of expenditure on menu costs is endogenous to the existing

In short, the literature has found that menu costs – even when only examining their most measurable manifestation – are no small matter.

4.3 Nonconvex menu costs vs. convex (Rotemberg) menu costs

In this subsection, we continue the comparison of optimal policy under menu costs to optimal policy in standard models. This will not only clarify our results but also will shed new light on the existing literature.

Throughout this paper, we have used a model of "nonconvex menu costs": the cost of price adjustment is *fixed* and does not scale with the size of a price change (Barro 1972; Sheshinski and Weiss 1977). That is, the menu cost facing a firm is a *nonconvex* function of the size of its price change. Contrast this model with models of *convex* menu costs, where the cost of price adjustment depends on the magnitude of the desired price change, and this cost is convex in that magnitude.

Consider the canonical model of convex menu costs, the Rotemberg (1982) model of quadratic menu costs, where the menu cost scales with the square of the size of the price change:

$$\psi \cdot (p_i - p_i^{ss})^2$$

In contrast, in the model we present above, the menu cost is constant as a function of the size of the price change: where $\mathbb{I}$ represents the indicator function,

$$\psi \cdot \mathbb{I}\{p_i \neq p_i^{ss}\}$$

It is well known that the single-sector Rotemberg convex menu cost model is isomorphic in its structural equations, to a first-order approximation, to the textbook New Keynesian model built on the Calvo time-dependent friction.[19] Furthermore, the model is isomorphic to a second-order approximation in its optimal policy implications to the Calvo model (Nisticò 2007), i.e. inflation targeting not wage targeting is optimal.

Why do Rotemberg *convex* menu costs imply inflation targeting is optimal, while our *nonconvex* menu costs imply nominal wage targeting is optimal?

The difference comes directly from the convex nature of the Rotemberg menu costs:

---

monetary policy regime, as proposition 1 emphasizes.

[19]Do note however that the *mechanism* of the Rotemberg model is very different from the Calvo model. Under Calvo, the welfare loss of bad monetary policy is the resulting relative price dispersion: total factor productivity is effectively lower. Under Rotemberg – and in our model – instead, the loss comes from the real resource cost of menu costs.

due precisely to the convexity, it is better to have all sectors adjust prices a little than to have one sector do all of the adjustment. With the nonconvex menu costs of our model, it is instead optimal to minimize the number of sectors which choose to adjust at all.

The key intuition is in the labor market clearing condition. The labor market clearing condition in the multisector Rotemberg model is:

$$N = \sum_{i=1}^{S} n_i + \psi \sum_{i=1}^{S} (p_i - p_i^{ss})^2 \tag{21}$$

This contrasts with the labor market clearing condition under nonconvex menu costs, our equation (14):

$$N = \sum_{i=1}^{S} n_i + \psi \sum_{i=1}^{S} \mathbb{I}\{p_i \neq p_i^{ss}\}$$

Under both Rotemberg and nonconvex menu costs, it is desirable to minimize the amount of menu costs because of the disutility of labor they create. Due to the *convex* nature of the Rotemberg menu costs in (21), it is better to *smooth* the price changes over all sectors: it is better to have a small price change in every sector, rather than a large price change in one sector. Under nonconvex menu costs, it is instead better to minimize the *number* of sectors which experience any price change. It is this difference – convex versus nonconvex costs of adjustment – which explains the differing optimal policy prescriptions.

4.4   Reexamining optimal policy in the Calvo model

Finally, we come to why optimal policy in the menu cost setting differs from optimal policy in the textbook Calvo model (Woodford 2003; Rubbo 2023).

Consider the analogy to the Rotemberg model. As discussed in the prior subsection, it is known that optimal policy under the Rotemberg and Calvo frictions are the same: inflation targeting. We also explained that the Rotemberg model and the fixed menu cost model have differing optimal policy implications because Rotemberg assumes a *convex* menu cost, implying that price changes should be spread over many sectors rather than concentrated in one sector.

Similarly, in the Calvo model, *the welfare cost of price dispersion is convex*. While a perfectly clean comparison with the menu cost model cannot be made due to the differing nature of the models – unlike the comparison of (21) versus (14) – the intuition can still be seen in the welfare-theoretic notion of price dispersion from the Calvo model. As stan-

dardly defined, price dispersion under Calvo is defined as:

$$\Delta \equiv \sum_{i=1}^{S} \int_0^1 \left[\frac{p_i(j)}{p_i} \right]^{-\eta} dj \tag{22}$$

Here, $\eta > 1$ continues to be the within-sector elasticity of substitution; and recall $p_i(j)$ is the nominal price of firm j in sector i, which now is heterogeneous within a sector thanks to the Calvo friction.

In the Calvo price dispersion formula, the convexity can be seen mathematically from the fact that the within-sector elasticity of substitution is positive (in fact, it is greater than unity). It is better to have many goods with slightly distorted prices, rather than to have few goods with highly distorted prices.[20]

Illustration. This discussion is illustrated in figure 1. The figure depicts the level of sectoral prices p_i in a three-sector Calvo model where production technology is constant returns to scale and sectors have symmetric parameters. Marginal cost is, as in (11), W / A_i.

In subfigure 1a, the economy is at steady state, where by assumption all sectoral productivities and prices are equal. That is, if we normalize $W^{ss} = 1$ and $A_i^{ss} = 1$ as in section 2.7, then $p_i^{ss} = 1$.

We then consider an increase in productivity in sector 1 to $A_1 = \gamma > 1$. Subfigure 1b shows what would happen under flexible prices: firms in sector 1 would cut prices, while firms in other sectors remain unchanged. That is, $p_1 = 1/\gamma < 1$ and $p_k = 1$.[21]

Subfigure 1c shows what would happen to sectoral prices in the Calvo sticky-price world under nominal wage targeting. Firms in sector 1 want to cut their prices to the flexible-price level. However, only some fraction of firms in that sector may do so, thanks to the Calvo friction. Other firms remain stuck at the steady state price, and have the wrong price. This creates within-sector price dispersion – the blue area in sector 1 is not uniformly the same height – as well as incorrect relative prices between the unchanged sector-1 firms and firms in other sectors. However, there is no within-sector price dispersion in other sectors: the green area in sector 2 has a uniform height, as does the purple area in sector 3. Firms in unshocked sectors are thus not affected by the shock.

Subfigure 1d shows what happens to sectoral prices in the Calvo world under inflation

---

[20]In the two-period, symmetric multisector Calvo model, the welfare loss function has three terms: (1) within-sector misallocation; (2) cross-sector misallocation; (3) the output gap. The within-sector misallocation reflects the convex costs of (22). The cross-sector misallocation is invariant to monetary policy. The output gap is proportional to the within-sector misallocation. Thus, the overall welfare loss function that a central bank seeks to minimize is proportional to (22).

[21]These flexible-price nominal formulas hold up to an unimportant scaling factor.
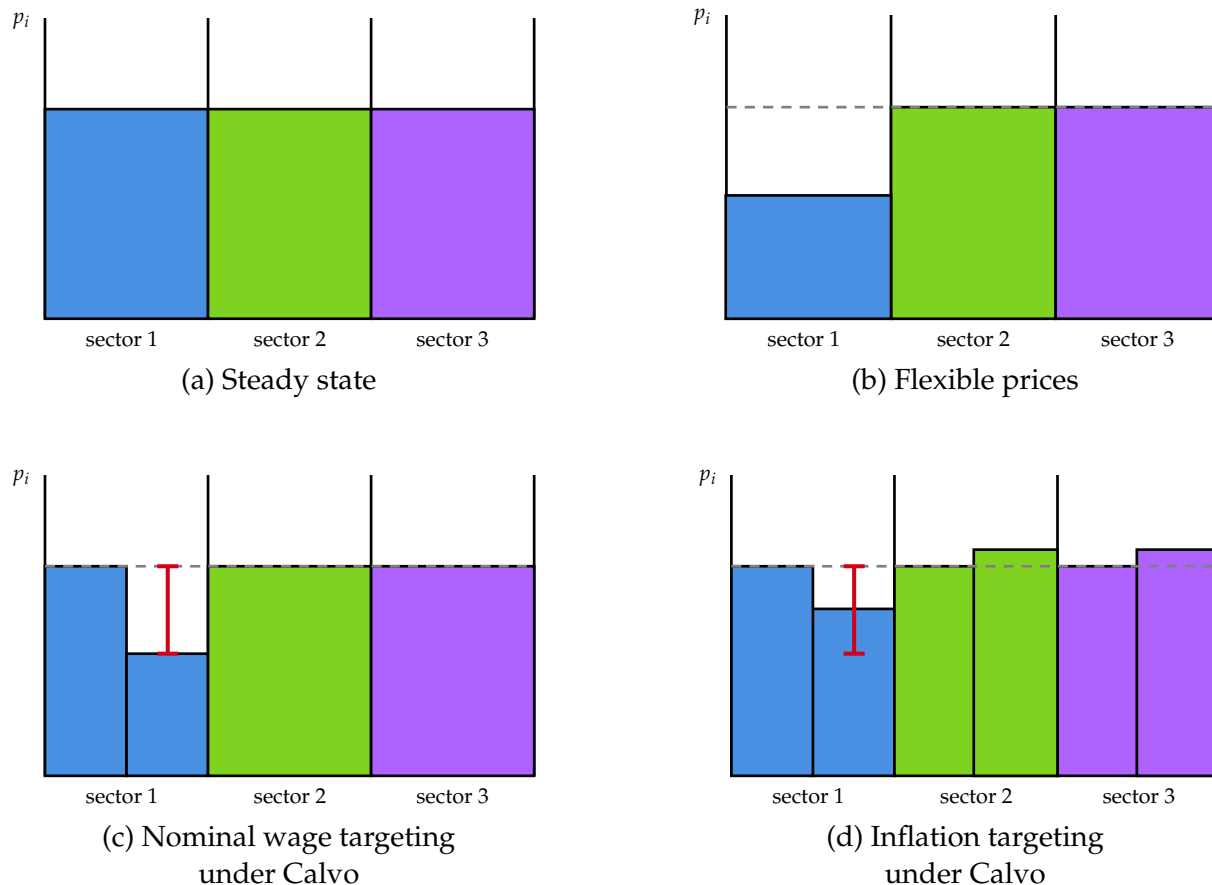
Figure 1: A stylized depiction of sectoral prices under Calvo in steady state (a), under flexible prices (b), under nominal wage targeting (c), and under inflation targeting (d). Nominal wage targeting (c) ensures that the shock to sector 1 does not spill over across sectors. Inflation targeting (d) minimizes total price dispersion by inducing unshocked sectors 2 and 3 to raise prices and thus is optimal.

targeting, which is the optimal policy in this setting. Now, monetary policy seeks to ensure that on average prices are unchanged. This requires the central bank to induce an increase in nominal wages. The result is that firms in sector 1 want to cut their prices, but not as much as under stable nominal wages; and firms in other sectors want to increase their prices. Because of the Calvo friction, only a fraction of firms in each sector is able to set the optimal price. As a result, there is within-sector dispersion in *all* sectors: every sector contains firms with differing prices.

As described above, the benefit of disturbing sectors 2 and 3 under inflation targeting is that *the sector-1 price dispersion is lessened*. That is, the gap in heights between the two blue bars is lessened compared to nominal wage targeting, as indicated by the red line. Because of the convexity of the welfare cost of this gap, the welfare benefit from this

decrease outweighs the incorrect prices induced in other sectors.

In short, the central bank does not "look through" the shock. Instead, it chooses to actively distort prices in unshocked sectors in order to reduce distortions in the shocked sector. The key to this logic is that the welfare loss is convex in the degree of distortion.

Future work. This suggests an important target for empirical work: *how convex are the costs of price changes* as a function of the size of the change? To our knowledge, this question has received no quantitative attention in the empirical literature cited in section 4.2.[22] Since the convexity of price adjustment costs has direct implications for the optimal target for monetary policy, this seems like an important gap to fill.

Additionally, future work could consider coordination frictions that dampen the ability of monetary policy to smooth shocks across sectors. The exogenous nature of the Calvo friction means that firms in unshocked sectors respond symmetrically to a movement in nominal wages induced by monetary policy as do firms in the shocked sector in response to the shock. More realistically, firms may more easily adjust prices following a productivity shock to their own sector, since they are more likely to be aware of it. This would be natural if productivity changes are in fact *endogenous*, rather than an exogenous shock; or in models of rational inattention where sectoral shocks typically receive more attention, endogenously, than aggregate shocks (Maćkowiak, Matějka and Wiederholt 2023).

5 Extensions to the benchmark model

We now consider several natural extensions to the model, which we continue to solve analytically. These showcase the robustness of our results, and are useful for reinforcing the intuition built above, regarding the mechanism of the results.

The core intuition argued above is that optimal monetary policy seeks to ensure that nominal marginal costs are unchanged for firms that do not receive a productivity shock, so that they have no desire to adjust their prices. This intuition is preserved even as the model is extended in various directions. What does change, however, is the formula for the nominal marginal cost for an unshocked firm.

5.1 Functional form generalizations

Consider the baseline model of section 2, but allow for the following generalizations:

---

[22] Zbaracki et al. (2004) has informal discussion.

1. Any constant returns to scale production technology for final goods, with (4) becoming $Y = F(y_1, ..., y_S)$ with F homogenous of degree 1

2. Potentially decreasing returns to scale in intermediate goods production technology, with (10) becoming $y_i(j) = A_i n_i(j)^{1/\alpha}$ with $1/\alpha \in (0, 1]$

3. Any household preferences quasilinear in labor, with (1) becoming $\mathbb{W} = U\left(C, \frac{M}{P}\right) - N$

Denote this as the generalized model.[23]

As in the baseline model, nominal marginal costs are an important object. Equilibrium nominal marginal costs can be derived as:

$$MC_i(j) = \left[\alpha \frac{W}{A_i^\alpha} \left(y_i p_i^\eta\right)^{\alpha-1}\right]^\theta \tag{23}$$

$$\theta \equiv [1 - \eta(1 - \alpha)]^{-1} \tag{24}$$

Observe that if α were equal to one, then $\theta = 1$ and $MC_i(j) = W/A_i$, as in equation (11) of the baseline model. In this more general model, marginal cost depends on not just wages and productivity, but also on demand. This is due to the decreasing returns to scale of the production technology.

As a result, optimal policy in this general model does not exactly stabilize nominal wages, but instead stabilizes nominal marginal costs (23) for unshocked sectors, as the next proposition describes. The intuition remains the same: ensuring that only the shocked sector adjusts and others do not minimizes the menu costs incurred by the economy.

Proposition 3 (Functional form generalizations). Consider again the positive productivity shock γ affecting sector 1, in the generalized model. For a fixed level of menu costs ψ, there exists a threshold level of productivity $\overline{\gamma} > 1$, such that:

1. If the productivity shock to sector 1 is above the threshold, $\gamma \geq \overline{\gamma}$, then optimal policy is to ensure the nominal marginal costs of firms outside sector 1 are unchanged.

---

[23]In the generalized model, the functional form for utility remains quasilinear in labor, as with Golosov-Lucas preferences. As discussed in section 3.1 and footnote 13, this is necessary to ensure that the income effects induced by menu costs do not distort the consumption-leisure margin. In the model of appendix B, where menu costs are modeled as a utility penalty and therefore do not reduce household income, preferences need not be quasilinear in labor and can be fully general. Alternatively, consider if menu costs are modeled as a loss of profits without transfer to the household (as in e.g. Alvarez et al. 2019). Then, we would want to ensure there is no income effect on *labor supply* rather than no income effect on consumption. In other words, preferences would have to be of the Greenwood, Hercowitz and Huffman (1988) form.

This results in firms in sector 1 adjusting their price, while firms in other sectors k leave prices unchanged.

2. If the shock is below the threshold, $\gamma \in [1, \bar{\gamma})$, then optimal policy is to ensure that prices remain unchanged and no firm in any sector adjusts.

Additionally, the productivity threshold $\bar{\gamma}$ is increasing in the size of menu costs ψ.

Proof: The proof follows exactly the same steps as in the proof of proposition 1. □

The statement of proposition 3 is precisely the same as the statement of proposition 1, except that instead of stabilizing *nominal wages* to ensure unshocked firms do not adjust, the central bank stabilizes the *nominal marginal costs* of unshocked firms. These marginal costs depend on demand, which is affected by the shock to sector 1.

An example. In the most abstract case, optimal policy cannot be characterized more sharply than proposition 3. However, it is instructive to consider a special case that is common in much of the optimal policy literature.

Suppose preferences over consumption and real balances are isoelastic; aggregation technology is Cobb-Douglas; and continue to allow for decreasing returns to scale technology:

$$\mathbb{W} = \frac{1}{1-\gamma} C^{1-\gamma} + \frac{1}{1-\gamma} \left(\frac{M}{P}\right)^{1-\gamma} - N$$

$$Y = \prod_{i=1}^{S} y_i^{1/S}$$

$$y_i(j) = A_i n_i(j)^{1/\alpha}$$

In particular, this differs from the baseline model by allowing for isoelastic preferences and also decreasing returns to scale.

In this example, it can be shown that marginal cost is a weighted average of nominal wages and the aggregate price level:

$$MC_i(j) = k \frac{W^{\xi} P^{1-\xi}}{A_i} \tag{25}$$

$$\xi \equiv \frac{\gamma + \alpha - 1}{\gamma \alpha} \tag{26}$$

where $k = \frac{1}{S}(\alpha S)^{1/\alpha}$.

Thus, in this specification, following a shock to sector-1 productivity alone, the central bank should stabilize $W^{\xi}P^{1-\xi}$. This means manipulating nominal wages W to offset any change in the aggregate price level P caused by the change in prices in sector 1. By holding steady $W^{\xi}P^{1-\xi}$, the central bank ensures nominal marginal costs are unchanged for firms outside sector 1, causing them to leave prices unchanged.

How much weight should the central bank give to stabilizing wages versus prices? We offer a more complete assessment in the quantitative model of section 6, but we may here consider a back of the envelope calculation. A typical calibration for γ, the inverse of the elasticity of intertemporal substitution, is $\gamma = 2$; a typical calibration for $1/\alpha$ is 0.6 to match the labor share. Plugging these values into (26) would result in the central bank putting a weight of $\xi = 0.8$ on stabilizing nominal wages, and a weight of $1 - \xi = 0.2$ on stabilizing inflation.

5.2 Sectoral heterogeneity and the "least-cost avoider" principle

We now return to the baseline setting and consider two kinds of heterogeneity, in sector size and menu cost magnitude, that lead us to a "least-cost avoider" interpretation of optimal monetary policy. We offer economic intuition on each in turn, and then state the result formally.

5.2.1 Heterogeneity in sector size

Suppose that sectors are of different sizes. Instead of each sector containing a continuum of firms on $[0, 1]$, allow sector i to range over $[0, S_i]$ for some finite S_i. We then denote $S \equiv \sum_i S_i$. Let everything else in the model remain as in the baseline model.

Heterogeneity in sector size affects the labor market clearing condition by interacting with menu costs, since larger sectors require hiring more labor to adjust prices:

$$N = \sum_i n_i + \psi \sum_i S_i \chi_i \qquad (27)$$

With this change, optimal policy is almost exactly that characterized in proposition 1. What differs is only in the extreme case when sector 1 is larger than all other sectors combined, $S_1 > \sum_{k>1} S_k$. Then if relative prices are to adjust it is actually optimal to have firms *outside* sector 1 adjust their price in response to a shock affecting sector 1 itself. That is because although it is only sector 1 which is affected by the shock, the combined mass of firms outside sector 1 is smaller than the mass of sector 1 itself. Therefore, the menu costs burned by having all other firms adjust their price is less than the menu costs burned

by having "just" sector 1 firms adjust.

Thus under the (extreme) assumption that sector 1 is larger than the combined mass of all other sectors, implementing the regime where 'only sectors k adjust' is preferable to implementing the regime where 'only 1 adjusts'. This has the same intuition that it achieves the correct relative prices while economizing on menu costs – where, here, economizing on menu costs means having sector 1 not adjust. This policy would not stabilize nominal wages or inflation.

We interpret this case as an illustration of the logic of our results, rather than an empirically-relevant case in general. Only in the case where *more than half* of the economy is *homogeneously* affected by the same shock does this result carry through. Otherwise, the optimal policy prescriptions of proposition 1 carry through exactly.

5.2.2 Heterogeneity in menu cost size

Introducing heterogeneity in menu cost size by sector is mostly similar. If the menu cost of sector i is ψ_i, labor market clearing (14) becomes:

$$N = \sum_i n_i + \sum_i S_i \psi_i \chi_i$$

Observe that the direct effect of heterogeneity in menu costs (ψ_i) on welfare is isomorphic to that of heterogeneity in sector size (S_i). But heterogeneity in menu cost size, unlike that in sector size, *also* affects the size of the inaction regions given in (13). However, this additional complication has a somewhat limited impact.

First – analogous to the possibility just discussed that sector 1 is very large in size – if the menu cost weighted size of sector 1 is large relative to those of other sectors, $S_1 \psi_1 > \sum_{k>1} S_k \psi_k$, then it is again optimal to have firms outside sector 1 adjust rather than those in sector 1. Second, variation in ψ_1 does affect when it is optimal to allow prices to go unchanged, i.e. affects the value of the threshold $\overline{\gamma}$.

5.2.3 Interpretation: a monetary "least-cost avoider" principle

We summarize both the above results in the following proposition.

Proposition 4 (Sectoral heterogeneity)**.** Suppose sector i is of size S_i and has menu cost ψ_i. Suppose further that the size-weighted menu cost of sector 1 is smaller than the combined weighted sum of menu costs for other sectors, $S_1 \psi_1 < \sum_{k>1} S_k \psi_k$. Then optimal monetary is exactly the same as characterized in proposition 1 modulo changes in the constant $\overline{\gamma}$.

Proof: Under the assumption about the magnitude of weighted menu costs, the proof follows exactly as in the proof of proposition 1. □

These two results on sectoral size and menu cost heterogeneity, summarized in proposition 4, can be interpreted as a "least-cost avoider" theory of optimal monetary policy. In the economic analysis of law, the least-cost avoider principal states that when considering assignment of liability between parties, it is efficient to assign liability to the party who has the lowest cost of avoiding harm (Calabresi 1970). Similarly, the generalized principle of optimal monetary policy under menu costs is: *the agents for whom it is least costly to adjust their price are the agents who should do so.*

More closely to the monetary economics literature, this is also very related to the idea that "monetary policy should target the stickiest price" (e.g. Mankiw and Reis 2003; Aoki 2001; Eusepi, Hobijn and Tambalotti 2011). Under menu costs, the central bank should minimize adjustment by the firms with the most expensive menu costs – i.e. it should stabilize the stickiest prices.

5.3 Multiple shocks

In the baseline exercise analyzed in proposition 1, we consider a shock to the productivity of sector 1 alone. One motivation for this is the idea that in reality productivity shocks arrive as Poisson shocks, separated by spans of time, with no two sectors ever being shocked at precisely the same time. However, such motivation introduces an intertemporal aspect that we do not study in the analytical model, although we will consider the role of dynamics in the quantitative results of section 6.

In this section, we consider the case where an arbitrary set of sectors is shocked, including possibly every sector. Start again at steady state, where every sector has productivity of $A_i^{ss} = 1$. We consider the exercise of shocking every sector to productivity A_i, where A_i could be potentially above, below, or equal to 1: it may be a positive shock, it may be a negative shock, or the sector may be unshocked.

Equilibrium. It is illustrative to consider a generic equilibrium when some fixed subset of sectors $\Omega \subseteq \{1, ..., S\}$ adjusts, while the remaining sectors do not adjust. Denote the cardinality of Ω as $\omega \equiv |\Omega|$. Sectors which adjust update their price to $p_i = M/A_i$, whereas others remain at the steady state value of $p_i^{ss} = 1$. The aggregate price level thus

aggregates from (6) to:

$$P = \frac{SM^{\omega/S}}{\prod_{i \in \Omega} A_i^{1/S}}$$

Using the quantity equation (2), gives consumption and output as:

$$C = Y = \frac{1}{S} \left[\prod_{i \in \Omega} A_i^{1/S} \right] M^{\frac{S-\omega}{S}}$$

For comparison, the flexible-price level of output is $Y_{\text{flex}} = \frac{1}{S} \prod_{i=1}^{S} A_i^{1/S}$. Using sectoral demand, production technology, and labor market aggregation, the amount of aggregate labor is:

$$N = \frac{\omega}{S} + \frac{M}{S} \sum_{i \notin \Omega} \frac{1}{A_i} + \psi\omega$$

Thus, welfare – conditional on the set Ω of sectors adjusting – as a function of the choice of money supply, is:

$$\mathbb{W}_{\Omega}(M) = \ln \left[\frac{1}{S} \left[\prod_{i \in \Omega} A_i^{1/S} \right] M^{\frac{S-\omega}{S}} \right] - \left[\frac{\omega}{S} + \frac{M}{S} \sum_{i \notin \Omega} \frac{1}{A_i} + \psi\omega \right] \quad (28)$$

As before allowing the social planner to overcome adjustment externalities, the optimal choice of money supply (conditional on Ω sectors adjusting) is found directly from the first order condition of (28).[24] The first order condition gives:

$$M_{\Omega}^* = \frac{S - \omega}{\sum_{i \notin \Omega} \frac{1}{A_i}} \quad (29)$$

Welfare under optimal policy, conditional on the set Ω of sectors adjusting, is:

$$\mathbb{W}_{\Omega}^* = \ln \left[\frac{1}{S} \left[\prod_{i \in \Omega} A_i^{1/S} \right] \left(\frac{S - \omega}{\sum_{i \notin \Omega} \frac{1}{A_i}} \right)^{\frac{S-\omega}{S}} \right] - [1 + \psi\omega] \quad (30)$$

Replicating the flexible-price allocation. Now, it is generically only possible to replicate the flexible-price allocation – aside from the extra labor required for menu costs – in two cases. First, as before, if all sectors adjust, i.e. $\Omega = \{1, ..., S\}$ and $\omega = S$, then

---

[24]As long as the number of sectors adjusting is not all S sectors, i.e. $\omega < S$. If all sectors adjust, i.e. if $\omega = S$ and $\Omega = \emptyset$, then welfare is independent of the choice of the money supply M.

naturally this ensures the flexible-price allocation. This comes at the cost of all S sectors paying the menu cost.

The flexible-price allocation can, however, be achieved also if $\omega = S - 1$, so all but one sector adjust. The one non-adjusting sector simply may be any arbitrary sector r. In this case, the central bank would set the money supply at $M = \frac{1}{A_r}$. This ensures that the desired price of sector r, that is $\frac{M}{A_r}$, equals the steady-state level of $p_r^{ss} = 1$, so that despite not changing its price, sector r has the price that it would choose if it were to adjust. This comes at the cost of $S - 1$ sectors paying the menu cost.

An immediate implication is that it is never optimal to have all S sectors adjust, since the same allocation can be achieved if $S - 1$ sectors adjust, but with less labor required for menu costs. In other words, it is always best to peg at least one sector and ensure that at least that one sector need not adjust its price. This sector may be arbitrarily chosen in the baseline model. If sectors were of heterogeneous size or had heterogeneous menu cost sizes, as in proposition 4, then it would be optimal to choose the sector with the largest size-weighted menu costs. This reinforces the "least-cost avoider principle" interpretation, or the "stabilize the stickiest price" interpretation described in that proposition.

If more than one sector leaves their price unchanged, i.e. $\omega < S - 1$, then it is usually not possible to achieve the flexible-price allocation. This is the standard result that when relative prices change, if there is sufficient nominal rigidity, the flexible-price allocation cannot be achieved: there is more than one target (the many relative prices), but only one instrument, M (Poole 1970).

Interpreting conditionally-optimal policy. Since it is still the case that nominal wages are determined by monetary policy, $W = M$, it follows from (29) that nominal wages *conditional on sectors Ω adjusting* are:[25]

$$W_\Omega^* = \frac{S - \omega}{\sum_{i \notin \Omega} \frac{1}{A_i}} \tag{31}$$

In other words, the equilibrium nominal wage under optimal policy depends on the central bank's choice of the set of adjusting firms Ω.

From (31), we can see that optimal policy will stabilize nominal wages, $W_\Omega^* = W^{ss}$, if all firms who do not adjust are unshocked (since $A_i = 1$ for unshocked sectors, and the cardinality of Ω is $S - \omega$).

Thus we can summarize optimal policy under multiple shocks as follows.

---

[25]For any Ω with $\omega < S$. With $\omega = S$, nominal wages are indeterminate and may be anything. We may then for simplicity choose the level given in (31).

Proposition 5 (Optimal policy with multiple shocks). Consider an arbitrary set of productivity shocks to the baseline model, $\{A_1, ..., A_S\}$.

1. Conditional on sectors $\Omega \subseteq \{1, ..., S\}$ adjusting, optimal policy is given by setting $M = M_\Omega^*$ defined in (29).

2. The optimal set of sectors that should adjust, Ω^*, is given by comparing welfare under the various possibilities for Ω, using $\mathbb{W}_\Omega^*$ defined in (30).

3. Nominal wage targeting is exactly optimal if the set of sectors which should not adjust, are unshocked: $A_i = 1 \ \forall i \notin \Omega^*$.

Even when optimal policy does not exactly stabilize nominal wages, it may nonetheless be considered to approximately do so. For $A_i \approx 1$, it is the case that $\frac{1}{A_i} \approx 1$; this implies that $\sum_{i \notin \Omega} \frac{1}{A_i} \approx \sum_{i \notin \Omega} 1 = S - \omega$, and so by (31) nominal wages are approximately unchanged, $W_\Omega^* \approx \frac{S-\omega}{S-\omega} = 1$. As in proposition 1, it will only be optimal to adjust for sectors which experience larger shocks. As a result, for unadjusting sectors, $i \notin \Omega$, it is particularly true that $A_i \approx 1$.

Ultimately, the performance of exact nominal wage targeting in the face of multiple shocks is in part an empirical question – depending on the distribution of shocks, and how tightly centered around 1 they are – and in part a quantitative question – depending on how well exact nominal wage targeting performs compared to the analytical optimal policy. We answer this question in the quantitative model of section 6.

5.4 Production networks

In this subsection, we consider a variant of the baseline model where intermediate firms use not just labor as a factor of production, but also use other goods as an input. We consider the symmetric roundabout economy of Basu (1995).

We need only alter the intermediate firm's problem. Suppose the production function of firm j in sector i is now:

$$y_i(j) = A_i n_i(j)^\beta I_i(j)^{1-\beta} \tag{32}$$

$$I_i(j) = \prod_{k=1}^{S} I_{ki}(j)^{1/S}$$

Here, $I_i(j)$ is the composite intermediate good used by firm j in sector i to produce output. It has weight $1 - \beta$ in production compared to β for labor; setting $\beta = 1$ returns us to the baseline model. The composite intermediate good is a bundle of outputs from every other sector: $I_{ki}(j)$ is output *from* sector k purchased by the firm j in sector i. Output from every

other sector is bundled into the symmetric Cobb-Douglas composite, which is used in production.

With input-output linkages, the marginal cost of a given firm now depends on not just wages but also on the price of every other good in the economy. The firm's problem now consists not only of choosing the price $p_i(j)$, but also choosing the input demand $n_i(j)$ and $I_i(j)$. These demand functions can be found from cost minimization.

It is easy to show that nominal marginal cost is a weighted average of nominal wages and the aggregate price index:

$$MC_i(j) = k\frac{W^\beta P^{1-\beta}}{A_i} \tag{33}$$

where $k = \frac{1}{(1-\alpha)^{1-\alpha}\alpha^\alpha}$. The marginal cost has a weight β on wages, reflecting labor's share of β in the production function (32). The price index has a weight $1 - \beta$, reflecting that intermediates have a share of $1 - \beta$ in the production function, and the average price of intermediates is precisely the average price of goods in the economy: i.e., the price index.

In response to the baseline shock affecting only sector 1, optimal policy thus is to stabilize this weighted average of wages and prices, with the weights determined by β. This parallels the example in section 5.1, where optimal policy also stabilized a weighted average of wages and prices. To get a sense of the implications for policy, we can consider off-the-shelf calibrations for β: Basu (1995) suggests β is at most 50%; Nakamura and Steinsson (2010) estimate that β is roughly 30%. In either case, nominal wages still are weighted substantially in the central bank's target.

Proposition 6 (Roundabout economy). Consider again the positive productivity shock γ affecting sector 1, in the baseline model augmented with the roundabout production technology of (32). For a fixed level of menu costs ψ, there exists a threshold level of productivity $\overline{\gamma} > 1$, such that:

1. If the productivity shock to sector 1 is above the threshold, $\gamma \geq \overline{\gamma}$, then optimal policy is to ensure the nominal marginal costs of firms outside sector 1 are unchanged. This is implemented by stabilizing $W^\beta P^{1-\beta}$. This results in firms in sector 1 adjusting their price, while firms in other sectors k leave prices unchanged.

2. If the shock is below the threshold, $\gamma \in [1, \overline{\gamma})$, then optimal policy is to ensure that prices remain unchanged and no firm in any sector adjusts.

Proof: The proof follows exactly the same steps as in the proof of proposition 1. □

37

5.5 Segmented labor markets

The economies considered so far displayed one labor market. In this subsection, we consider optimal policy in an economy with segmented labor markets. Specifically, a particular household can provide its labor to a single sector. While there is no unique wage the central bank can target, the generalized principle of least-cost avoidance holds: the central bank targets the wage in the unshocked sectors.

Setup. The production side of this economy is identical to that in the benchmark model. In contrast, households are heterogenous, there is a representative household for each sector. Therefore, households in sector i make their own decisions about consumption, labor supply, and money balance. Assume that firm dividends and government transfers are economy-wide. The problem household i faces is

$$W_i = \ln C_i - N_i + \ln \left(\frac{M_i}{P} \right) \tag{34}$$

subject to the budget constraint:

$$PC_i + M_i = W_i N_i + D + M_{-1} - T \tag{35}$$

The first-order conditions result in the usual conditions

$$PC_i = M_i \tag{36}$$
$$W_i = M_i \tag{37}$$

Consider now the baseline exercise in which sector 1 productivity increases to γ. For clarity, consider the case where γ is sufficiently large, so that we do not need to discuss an analog to the $\overline{\gamma}$ of proposition 1. In this economy, in which there are S-many wages, it is still better for the central bank to keep the wage of unshocked sectors constant than to keep the price level constant as proposition 7 states.

Proposition 7 (Segmented Labor Markets). Consider again the positive productivity shock γ affecting sector 1 in the baseline model augmented with segmented labor markets. In this economy, welfare is always higher when the central bank stabilizes wages in the unshocked sectors than when it stabilizes the price level by making all sectors adjust their prices.

Proof: See appendix C. ☐

5.6 Sticky wages

Throughout the paper thus far, we have considered a model with sticky prices and flexible wages; we now consider the case of flexible prices and sticky wages. Optimal policy in response to the same sectoral productivity shock continues to stabilize nominal wages, again in order stabilize the nominal marginal cost of unshocked sectors and thus minimize menu cost expenditure.

Setup. Consider the baseline model of section 2, but now allow for heterogenous types of labor organized into a union with wage-setting power. Suppose there are S labor sectors, and each goods-producing sector $i = 1, ..., S$ hires labor exclusively from the corresponding labor sector $i = 1, ..., S$. Within each labor sector, there is a continuum of differentiated worker types, indexed on $[0, 1]$. Continue to denote the total amount of labor used by goods-producing firm j in sector i as $n_i(j)$, and continue to endow intermediate firms with technology $y_i(j) = A_i n_i(j)$.

Firm-level labor input $n_i(j)$ is now, unlike in the baseline model, composed of a CES bundle of workers from labor sector i:

$$n_i(j) = \left[\int_0^1 \left(n_i^k(j) \right)^{\frac{\varepsilon-1}{\varepsilon}} dk \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

where $n_i^k(j)$ denotes the quantity of labor of type k in labor sector i hired by firm j in goods-producing sector i; and ε is the elasticity of substitution across labor types. Cost minimization produces the standard demand curve, $n_i^k(j) = \left(\frac{W_i(k)}{W_i} \right)^{-\varepsilon} n_i(j)$, where $W_i(k)$ is the nominal wage of labor type k in sector i and W_i is the wage index for sector i labor. This results in a profit function of $D_i(j) = p_i(j) y_i(j) - W_i n_i(j)$.

For firms in sector i, the optimal reset price (i.e. the nominal marginal cost) now depends on the *sector-specific* wage and sectoral productivity:

$$p_i^{\text{flex}}(j) = MC_i(j) = \frac{W_i}{A_i} \tag{38}$$

Because prices are now flexible – that is, firms face $\psi = 0$ – firms always set price equal to this optimal reset price.

The nominal wage for worker type j in sector i, $W_i(j)$, is set by a union which must pay a fixed cost for nominal wage changes: the "menu cost". This can be motivated by a fixed cost of contract renegotiation. The union's problem can be considered as part of the

representative household's problem, which is written as:

$$\max_{C,M,\{W_i(j)\}_{i,j}} \ln C + \ln\left(\frac{M}{P}\right) - \sum_{i=1}^{S} \int_0^1 N_i(j)dj$$

$$\text{s.t. } PC + M = (1+\tau^W)\sum_{i=1}^{S} \int_0^1 W_i(j)N_i(j)dj + M_{-1} + D - T - \psi^W\chi^W$$

$$N_i(j) = \left(\frac{W_i(j)}{W_i}\right)^{-\varepsilon} N_i$$

This utility maximization problem differs from that in section 2.1 in a few ways. The household sets nominal wages, given the demand curves for labor types, analogous to the price-setting problem of intermediate firms. The household receives a labor subsidy τ^W to offset the monopsony distortion from its wage-setting power, analogous to the labor subsidy that firms are given to offset the monopoly distortion from firm price-setting power. Finally, the household must pay a menu cost ψ^W if it wishes to change any wage, analogous to the menu cost facing firms. The variable χ^W measures the mass of wages which are changed:

$$\chi^W \equiv \sum_i \int_j \chi_i^W(j)dj$$

$$\chi_i^W(j) \equiv \mathbb{I}\{W_i(j) \neq W_i^{\text{old}}(j)\}$$

where $W_i^{\text{old}}(j)$ is the inherited nominal wage for type j in sector i, analogous to $p_i^{\text{old}}(j)$ in the firm's problem.

The optimality conditions of this optimization problem include the equation of exchange (2) but also a new condition for optimal wage-setting. Under the optimal labor subsidy of $\tau^W = \frac{1}{\varepsilon-1}$, the optimal wage-setting condition *conditional on adjusting* is determined by the marginal rate of substitution between consumption and leisure:

$$W_i^{\text{flex}}(j) = PC = M \quad \forall i,j \tag{39}$$

Note that under flexible wages, wages across types and sectors are all equalized.

In equilibrium, the wage menu cost paid by the household creates a wedge between consumption and output:

$$C = Y - \psi^W\chi^W \tag{40}$$

This aggregate resource constraint is derived from the household budget constraint and

market clearing conditions.

We summarize the important differences with the baseline model. First, the nominal marginal costs of the intermediate goods producers (38) now depend on a sector-specific wage, $MC_i(j) = W_i/A_i$. Firms always set price equal to this level because prices are flexible. Second, in the efficient flexible-wage equilibrium, all nominal wages are equalized from (39). Third, wage menu costs result in a wedge between consumption and output, from (40), and lower welfare.

Optimal policy after a sectoral shock. Consider again the same exercise: starting from a steady state with $A_i^{ss} = 1$ and $M = 1$, shock productivity of sector-1 goods producers, $A_1 = \gamma > 1$. For clarity, consider the case where γ is sufficiently large, so that we do not need to discuss an analog to the $\overline{\gamma}$ of proposition 1.

The optimal reset prices and wages – i.e., those that would prevail in the frictionless equilibrium – are:

$$
p_1^{\text{flex}}(j) = \frac{W_1}{\gamma}
$$
$$
p_k^{\text{flex}}(j) = W_k \quad \forall k > 1
$$
$$
W_i^{\text{flex}}(j) = M \quad \forall i, j
$$

To minimize the amount of menu costs and simultaneously achieve correct relative prices, it is again desirable to leave M unchanged, thereby stabilizing nominal wages. This ensures that no wages need to be adjusted and no wage menu costs need to be paid: that is, $W_i = W_i^{ss}$ for all i. Meanwhile, given the shock was assumed to be sufficiently large, goods-producing firms in sector 1 can update their prices, thus ensuring all relative prices are correct.

In short, optimal policy stabilizes all nominal wages, which ensures correct relative prices and causes only sector-1 firms to adjust.

5.7   Optimal policy without selection effects

The existence (or not) of selection effects in menu cost models is an important question in the literature, due to the argument that selection effects reduce monetary non-neutrality relative to models with time-dependent pricing like the Calvo model (Golosov and Lucas 2007; Caballero and Engel 2007; Carvalho and Kryvtsov 2021; Karadi, Schoenle and Wursten 2022; Gautier et al. 2022). The question this literature generally considers is: in response to a *monetary policy shock*, how much is real output affected? On the other

hand, under optimal monetary policy naturally there are no monetary shocks.

In this subsection, we show that the existence or not of selection effects plays little role. We demonstrate this by briefly characterizing a "CalvoPlus" variant of the baseline model (Nakamura and Steinsson 2010). In the CalvoPlus variant, the setup is precisely as in section 2, except that menu costs are now idiosyncratic at the firm level, $\psi_i(j)$. In particular, a random fraction $\zeta \in (0,1)$ of firms in each has an opportunity to adjust price for free, $\psi_i(j) = 0$; other firms face the nonzero menu cost, $\psi_i(j) = \psi$.

As the next proposition describes, optimal policy is in essence the same as in the baseline result of proposition 1, though the threshold $\overline{\gamma}$ is altered.

Proposition 8 (Optimal policy under CalvoPlus)**.** Consider the baseline model, modified so that a random fraction $\zeta \in (0,1)$ of firms in each sector face no menu cost, $\psi_i(j) = 0$, and remaining firms face $\psi_i(j) = 1$. For a fixed level of menu costs ψ, there exists a threshold level of productivity $\overline{\gamma}_{\text{CalvoPlus}} > 1$, such that:

1. If the productivity shock to sector 1 is above the threshold, $\gamma \geq \overline{\gamma}_{\text{CalvoPlus}}$, then optimal policy is exactly nominal wage targeting: monetary policy should ensure $W = W^{ss}$. This results in all firms in sector 1 adjusting their price, while all firms in other sectors k leave prices unchanged regardless of whether they have a free adjustment.

2. If the shock is below the threshold, $\gamma \in [1, \overline{\gamma}_{\text{CalvoPlus}})$, then optimal policy is to ensure that prices remain unchanged for firms with a nonzero menu cost, $\psi_i(j) > 0$.

3. The threshold $\overline{\gamma}_{\text{CalvoPlus}}$ is smaller than in the baseline model:

$$\overline{\gamma}_{\text{CalvoPlus}} < \overline{\gamma} \tag{41}$$

We sketch the proof to provide economic intuition. The logic follows very closely to the proof of proposition 1.

By stabilizing W, the central bank ensures that the nominal marginal cost of unshocked firms remains unchanged. Unshocked firms thus have no desire to change price, even if they have a free opportunity to do so. In this case, correct relative prices are achieved, at a welfare cost of $(1 - \zeta)\psi$ quantity of menu costs. For large enough shocks, this is optimal, because the welfare gains from correct relative prices outweighs the loss from paying the $(1 - \zeta)\psi$ menu cost.

For small shocks, however, menu costs are too costly to be worthwhile. In this case, firms with a free adjustment will adjust – creating within-sector price dispersion – but it is optimal to ensure that firms with a nonzero menu cost do not adjust. In fact, *within*

this case, the equilibrium is as-if Calvo: an exogenous fraction of firms in each sector is allowed to update prices for free, and the remaining firms do not adjust – here, endogenously, unlike Calvo. Optimal policy thus precisely replicates the Calvo optimum, *if* $\gamma < \overline{\gamma}_{\text{CalvoPlus}}$.

Observe that in the case where firms in sector 1 adjust, the welfare loss from menu costs is $(1 - \zeta)\psi$, which is smaller than the level of ψ in the non-CalvoPlus economy. Thus, the fixed welfare loss from menu costs in this case is smaller. As a result, the increase in productivity needed to make price adjustments overcome this welfare loss is correspondingly smaller. This explains the third part of the proposition.

6   Quantitative model

In this section, we develop a dynamic version of our baseline model, augmented with idiosyncratic shocks and calibrated to the US economy.

6.1   Model description and solution method

Our dynamic multisector model of menu costs is similar to that in Nakamura and Steinsson (2010). The main difference is that we include sector-specific productivity shocks on top of idiosyncratic, firm-level shocks. To solve for the aggregate dynamics of the economy, we use the sequence-space Jacobian approach of Auclert et al. (2021).

Household.   The household chooses paths for consumption, C_t, labor N_t, money balances, M_t, and bonds, B_t, to maximize the present discounted value of utility. The problem faced by the household is:

$$\max_{\{C_t, N_t, B_t, M_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\gamma}}{1-\gamma} - \omega \frac{N_t^{1+\varphi}}{1+\varphi} + \ln\left(\frac{M_t}{P_t}\right) \right] \tag{42}$$
$$\text{s.t.} \quad P_t C_t + B_t + M_t \leq R_t B_{t-1} + W_t N_t + M_{t-1} + D_t - T_t$$

This problem represents a dynamic version of the static household problem in section 2.1, with more general preferences. To consume and save (the left hand side of the budget constraint) the household uses gross wealth, money holdings, labor earnings, and firm dividends net of the lump sum tax imposed by the government (the right hand side of the budget constraint). R_t is the nominal interest rate on bonds.

Firms. The final good producer and sectoral good producers behave the same as in the baseline analytical model of section 2. These firms operate in competitive environments and aggregate the goods produced by the corresponding lower-tier firms according to the technologies:

$$Y_t = \prod_{i=1}^{S} y_{it}^{1/S} \tag{43}$$

$$y_{it} = \left[\int_0^1 y_{it}(j)^{\frac{\eta-1}{\eta}} \, dj \right]^{\frac{\eta}{\eta-1}} \tag{44}$$

Intermediate firms. A first key difference with the baseline model is that intermediate firms are now subject not only to sector-level productivity shocks, A_{it}, but also to idiosyncratic, firm-level shocks, $a_{it}(j)$. Log firm-level idiosyncratic productivity shocks follow a mixture between an AR(1) process and a uniform distribution, namely

$$\log\left(a_{it}(j)\right) = \begin{cases} \rho_{\text{idio}} \log\left(a_{it-1}(j)\right) + \varepsilon_{it}^{\text{idio}}(j) & \text{with prob. } 1 - \varsigma \\ \mathcal{U}\left[-\log\left(\underline{a}\right), \log\left(\bar{a}\right)\right] & \text{with prob. } \varsigma \end{cases} \tag{45}$$

where the innovations in the AR(1) process are Gaussian, $\varepsilon_{it}^{\text{idio}}(j) \sim \mathcal{N}\left(0, \sigma_{\text{idio}}^2\right)$.

A second key difference is that while firms usually have to pay a menu cost to adjust their prices, occasionally – with probability ν each period – they receive the chance to adjust for free (the "CalvoPlus" model). With probability $1 - \nu$, it faces the usual menu cost of ψ labor hours. If a firm chooses not to adjust in period t, $\chi_{it}(j) = 0$, it inherits its price $p_{i,t-1}(j)$ from the previous period. The problem facing intermediate firms is:

$$\max_{p_{it}(j)} \sum_{t=0}^{\infty} \mathbb{E}\left[\frac{1}{R^t P_t} \left\{ p_{it}(j) y_{it}(j) - W_t n_{it}(j)(1-\tau) - \chi_{it}(j)\psi_{it}(j) W_t \right\} \right] \tag{46}$$

$$\text{s.t.} \quad \chi_{it}(j) = \begin{cases} 1 & \text{if } p_{it}(j) \neq p_{it-1}(j) \\ 0 & \text{otherwise} \end{cases}$$

$$\psi_{it}(j) = \begin{cases} \psi & \text{w/ prob. } 1 - \nu \\ 0 & \text{otherwise} \end{cases} \tag{47}$$

$$y_{it}(j) = y_{it} \left(\frac{p_{it}(j)}{p_{it}} \right)^{-\eta}$$

$$y_{it}(j) = A_{it} a_{it}(j) n_{it}(j)^{\alpha} \tag{48}$$

$$R^t = \prod_{z=0}^{t} R_z$$

where τ is again the labor subsidy. Note that production technology (48) may have decreasing returns to scale, $\alpha \in (0, 1]$.

Market clearing. As in the baseline model, labor market clearing requires that labor supplied by the household equals labor used in production plus labor used in menu costs:

$$N_t = \sum_i \int_0^1 n_{it}(j)dj + (1-v)\psi\chi_t \tag{49}$$

where χ_t is the mass of firms that adjust prices in period t:

$$\chi_t \equiv \sum_i \int_0^1 \chi_{it}(j)dj \tag{50}$$

Solution method. To solve the model numerically, we use the sequence-space Jacobian method developed in Auclert et al. (2021). This method provides linearized general equilibrium responses with respect to perfect-foresight shocks to aggregate variables, while allowing agents' decision rules to be nonlinear with respect to idiosyncratic variables.[26] Note that, by certainty equivalence, the linearized perfect-foresight transition paths that we show here are equal to the first-order perturbation solution of the model with aggregate risk.

6.2 Calibration

The model is calibrated to match salient micro and macro moments of the US economy at the monthly frequency. There are two sets of parameters. The first set of parameters is standard and taken from the macroeconomics literature. The second is calibrated to match price-adjustment behavior by US firms. The model parameters are listed in table 1.

The preference parameters are set to standard values. The discount factor $\beta = 0.99835$ is chosen to match a 2% annualized interest rate. The disutility of labor is $\omega = 1$, the inverse Frisch elasticity is $\varphi = 0$ as in Golosov and Lucas (2007), and the inverse elasticity of intertemporal substitution is $\gamma = 2$.

Following Nakamura and Steinsson (2010), we choose $S = 6$ sectors. We assume the sectors are identical in their structural parameters: firms in different sectors are subject to the same idiosyncratic productivity processes and face the same menu cost. However, sectors are subject to heterogeneous sectoral shocks. The elasticity of substitution across

---

[26]The term "aggregate variables" refers to any non-idiosyncratic variable. In particular, it includes sectoral variables.

goods within sector is $\eta = 5$ and the decreasing return to scale parameter is $\alpha = 0.6$. The labor subsidy $\tau = \frac{1}{\eta} = 0.2$ is set to offset the markup distortion.

We estimate the five key parameters of the firm's problem to target key price-setting moments from the data. Those estimated parameters are the standard deviation and persistence of idiosyncratic productivity shocks, σ_{idio} and ρ_{idio}; the size of the menu cost ψ; the probability a firm can choose its price for free, ν; and the fat tail parameter, ς. These parameters are set to match six targets. First, per the literature cited in section 4.2, we target a menu cost expenditure as a share of firm revenue of 1%. Second, following Nakamura et al. (2018), we target the share of firms changing prices any given month (excluding sales) of 10.1%. Additionally, we target the first, second, and third quartiles of the absolute price change distribution, at 5.6%, 7.9%, and 12.5%, respectively. Finally, we target the kurtosis of the price change distribution of 5.1 taken from Nakamura and Steinsson (2008).

The last cell in table 1 shows that the target moments and, in parentheses, the model moments. The model matches the target moments well. The resulting estimated parameters are $\sigma_{\text{idio}} = 0.058$, $\rho_{\text{idio}} = 0.992$, $\psi = 0.1$, $\nu = 0.09$, and $\varsigma = 0.001$.

	Parameter (monthly frequency)	Value	Target	
β	Discount factor	0.99835	2% annual interest rate	
ω	Disutility of labor	1	standard	
φ	Inverse Frisch elasticity	0	Golosov and Lucas (2007)	
γ	Inverse EIS	2	standard	
S	Number of sectors	6	Nakamura and Steinsson (2010)	
η	Elasticity of subst. between sectors	5	standard value	
α	Returns to scale	0.6	standard value	
τ	Labor subsidy	0.2	$1/\eta$	
σ_{idio}	Standard deviation of idio. shocks	0.058	menu cost expenditure / revenue	1.0 (1.1%)
ρ_{idio}	Persistence of idio. shocks	0.992	share of price changers	9.7 (10.1%)
ψ	Menu cost	0.1	median absolute price change	8.3 (7.9%)
ν	Calvo parameter	0.09	Q1 absolute price change	4.2 (5.6%)
ς	Fat tail parameter	0.001	Q3 absolute price change	12.0 (12.5%)
			kurtosis of price changes	5.4 (5.1)

Table 1: Model parameters and baseline calibration (monthly frequency). The first two columns list the parameter symbols and descriptions. The third column presents the calibrated values, while the fourth column specifies the corresponding targets. In the last row, the model-implied value of the target is shown, with the empirical data value in parentheses.

6.3 A one-sector shock

Our goal is to compare the performance of nominal wage targeting versus inflation targeting. We begin with the dynamic analog to the exercise considered in section 3: a positive productivity shock to sector 1, of an arbitrary size.

Prices and quantities. Starting from the stationary distribution, consider a shock to sector-1 productivity A_1 of 1% which decays exponentially. Sectoral productivity is unshocked for all other sectors, while idiosyncratic shocks continue for all firms. Figure 2 displays the time paths of A_1, consumption, labor, and prices in percentage point deviations from steady state. Three cases are depicted: nominal wage targeting, inflation targeting, and flexible prices.
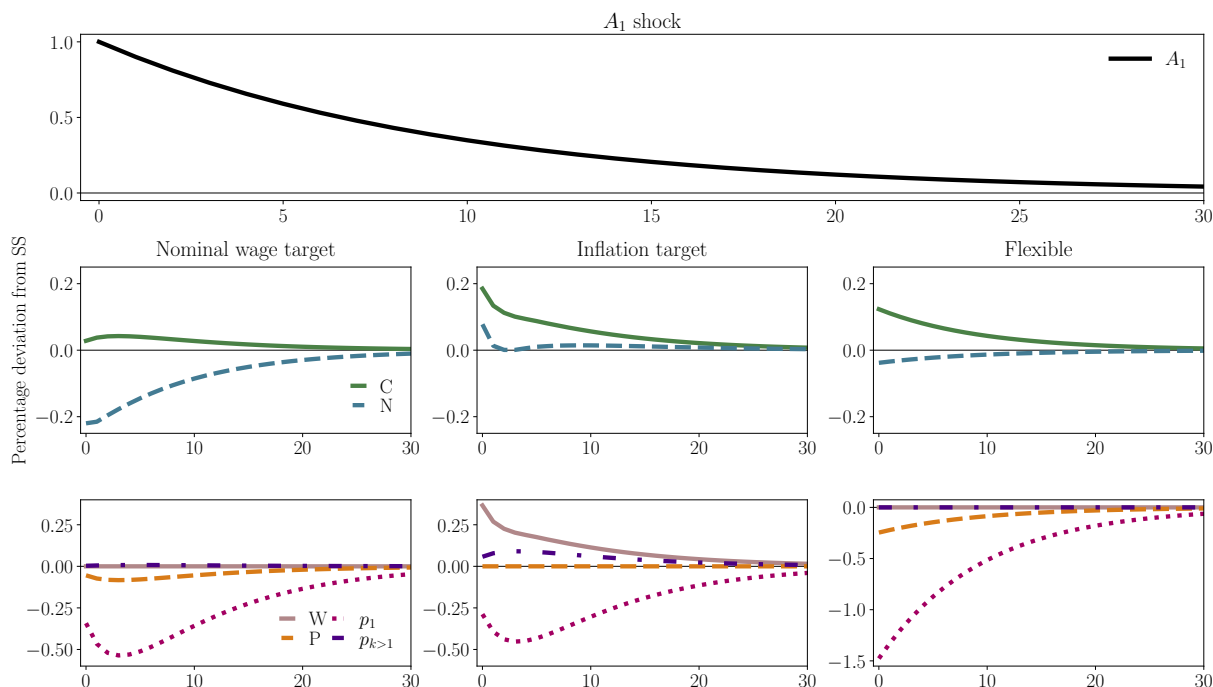

Figure 2: Sector-1 sectoral productivity is increased by a 1% shock which decays at exponential rate. The first column shows outcomes under nominal wage targeting; the second under inflation targeting; and the third column under the flexible-price benchmark.

Observe in the first column that under nominal wage targeting, besides nominal wages W remaining stable, the aggregate price level P falls in response to the positive productivity shock, driven almost entirely by the fall in sector-1 price p_1. Meanwhile, under inflation targeting in the second column, P is constant and W rises, driven by a fall in p_1 and an increase in all other sectoral prices p_k. What matters for welfare, however, are consumption and labor. Labor falls under nominal wage targeting and rises under inflation

targeting, a difference that is largely explained by differences in menu cost expenditure, discussed in the next subsection.

As a benchmark for comparison, the third column shows the impulse responses under flexible prices, in which $\psi = 0$. In this economy, we also normalize steady state sectoral productivity, A_i^{ss} so that steady state welfare in this flex-price economy exactly matches steady state welfare in the menu cost model.[27]

Observe that output (and consumption) follows a hump-shaped response under nominal wage targeting but not in either of the other two regimes.

Menu cost expenditure. The total quantity of labor N depicted above can be decomposed into labor used in production and menu cost expenditure. The first panel of figure 3 shows total labor (solid) and labor directed towards changing prices (dashed) under inflation (blue) and nominal wage (red) targets following the A_1 shock described above. The second panel plots the dynamics of total menu cost expenditures under the two regimes, that is $\sum_{i=1}^{S} \int_j \psi \chi_i(j)$.
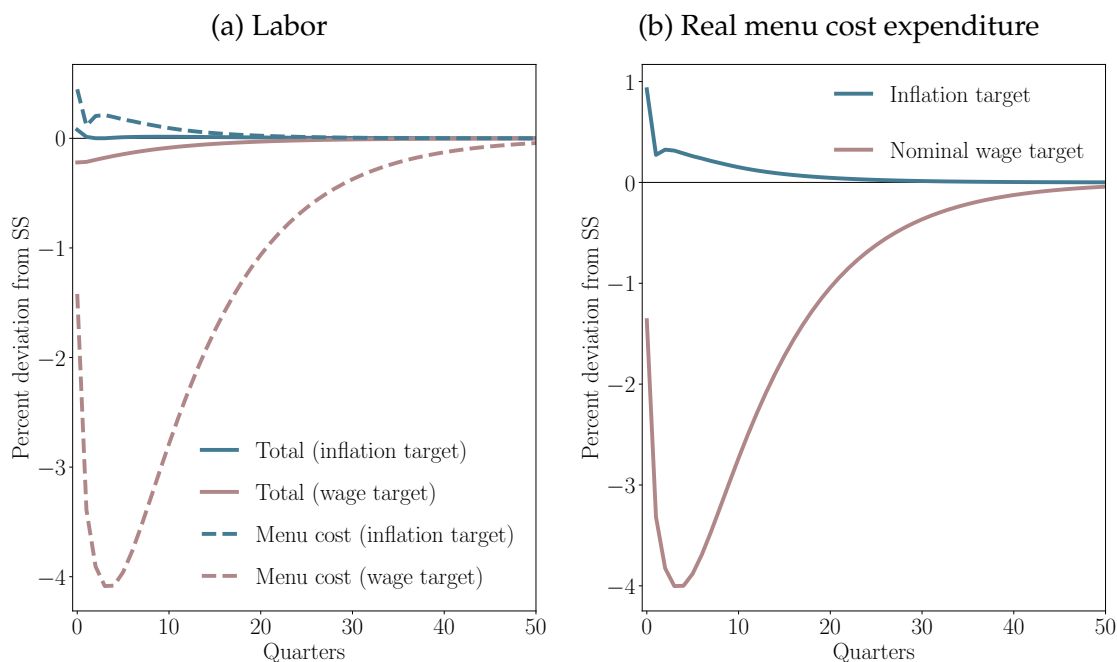

Figure 3: Panel (a) shows the percent deviation from steady state in labor used on menu costs (dashed) and overall (solid) after a persistent 1% increase in A_1, under nominal wage targeting (red) and inflation targeting (blue). Panel (b) shows the real menu cost expenditures under nominal wage (red) and inflation (blue) targeting.

---

[27] $A_i^{ss} = 1$ in the menu cost economy and $A_i^{ss} = 0.9779$ in the flex-price economy.

The labor employed in price changes is notably larger under inflation targeting than under nominal wage targeting, indicating that, following the productivity shock, the menu costs expended under inflation targeting are larger than those expended under nominal wage targeting. This is confirmed in the right panel of the figure which displays *real* menu cost expenditures in both regimes. This result agrees with the intuition from the static model that wage targeting economizes on menu cost expenditures.

Welfare. Through labor demand, menu cost expenditures, determine, along with consumption, the welfare response to the productivity shock, which is shown in figure 4.
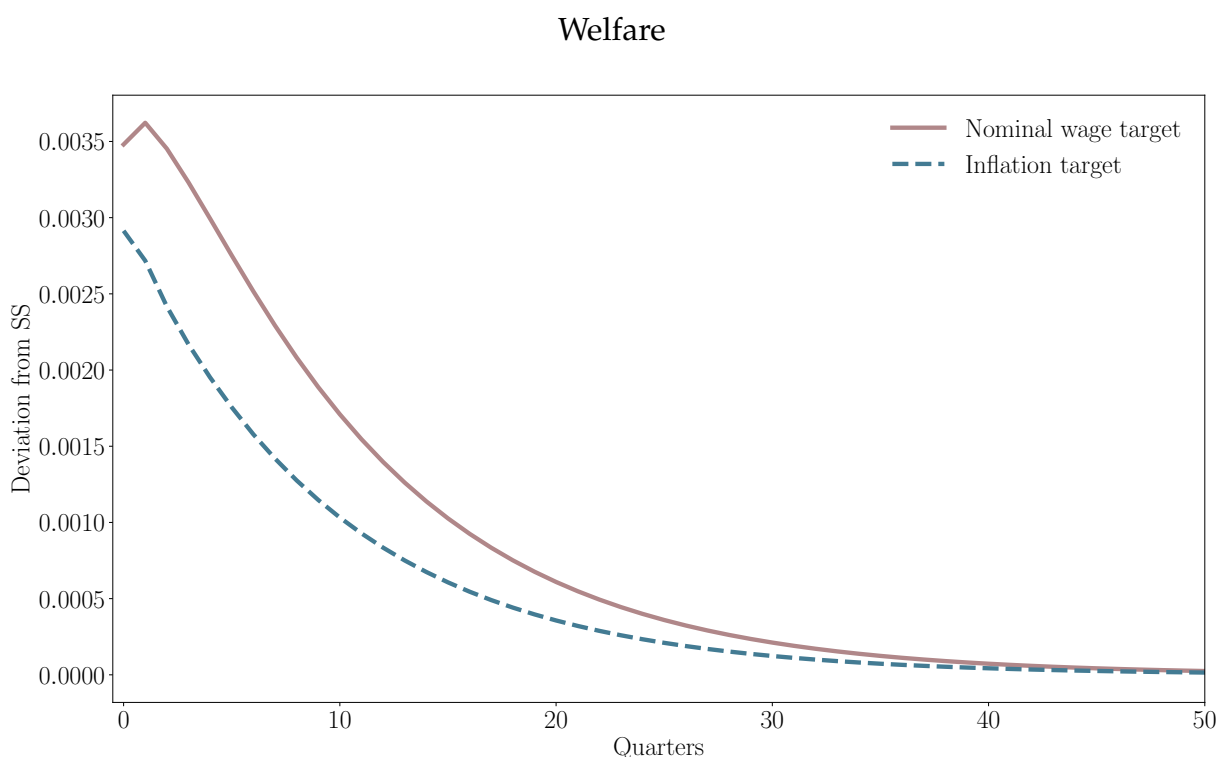

Welfare

Figure 4: Deviation from steady state in welfare after the persistent 1% increase in A_1 under nominal wage targeting, under inflation targeting targeting, and in the flex-price benchmark.

The welfare response under nominal wage targeting is higher than under inflation targeting. To make the gain in welfare from moving from an inflation targeting regime to a nominal wage targeting regime interpretable, we convert the welfare differences to consumption units. Denote the paths for consumption and labor as $\{C_t^x\}$ and $\{N_t^x\}$, respectively, where x refers to either nominal wage or inflation targeting $x \in \{W, P\}$. Denote the household period utility function from (42) as $U\left(C_t^x, N_t^x\right)$.

We ask: how much higher would the path for consumption need to be, such that lifetime household welfare under inflation targeting equals that under nominal wage targeting? That is, to a first-order approximation, what is the λ^x which solves:

$$\sum_{t=0}^{\infty} \beta^t U\left(\left(1+\lambda^P\right) C_t^P, N_t^P\right) = \sum_{t=0}^{\infty} \beta^t U\left(C_t^W, N_t^W\right) \tag{51}$$

We find that $\lambda^P = 0.008\%$, for this arbitrary 1% shock to sector-1 productivity.[28] This number is positive, indicating a welfare improvement moving from inflation to nominal wage targeting.

6.4 Policy over the business cycle

While the above exercise helps clarify the sources of the welfare improvement moving from inflation to wage targeting, the business cycle is characterized not by one shock to one sector but by sequences of shocks to all sectors. To mimic the business cycle, we postulate that sectoral productivity follows an AR(1):

$$\log(A_{it}) = \rho_{\text{sec}} \log(A_{it-1}) + \varepsilon_{it}^{\text{sec}} \tag{52}$$

where ρ_{sec} is the persistence parameter, and $\varepsilon_{it}^{\text{sec}} \sim \mathcal{N}(0, \sigma_{sec}^2)$.

We calibrate these parameters to match the dynamics of industrial production in the United States from January 1984 to December 2019. In doing so, it is important to recognize that aggregate shocks, which affect all sectors alike, also contribute to business cycle fluctuations. Garin, Pries and Sims (2018) find that aggregate shocks explain 31.5% of the variance in industrial production over this same time period. Therefore, we estimate σ_{sec} and ρ_{sec} to match the persistence in the cyclical component of industrial production, but only 68.5% of the variance in the cyclical component of industrial production. The resulting estimates are $\sigma_{\text{sec}} = 0.003$ and $\rho_{\text{sec}} = 0.962$. Simulating sequences of sectoral

---

[28]Since we are working with first-order approximations, λ has an analytical formula. First, define Δ as the first-order approximation to the difference between welfare under the two regimes, i.e. the first-order approximation to $\sum_{t=0}^{T} \beta^t \left[U\left(C_t^P, N_t^P\right) - U\left(C_t^W, N_t^W\right)\right]$. Then:

$$\lambda = \frac{1}{\sum_{t=0}^{T} \beta^t} \frac{1}{C^{ss} U_C\left(C^{ss}, N^{ss}\right)} \Delta$$

$$\rightarrow (1-\beta) \frac{1}{C^{ss} U_C\left(C^{ss}, N^{ss}\right)} \Delta$$

where C^{ss}, N^{ss} refer to the steady state variables in the sticky price economy. The interpretation of λ can be seen here: it takes the utility difference Δ, converts it to consumption units by dividing by steady state marginal utility U_C, and takes the ratio with steady state consumption C^{ss}.

productivity shocks we compute welfare and determine how much higher consumption needs to be under inflation targeting to mimic welfare under the wage targeting regime. The multiplier $\lambda^P = 0.32\%$, that is consumption would need to be 0.32% higher under inflation targeting to achieve the same welfare of the nominal wage targeting regime.

7 Conclusion

Summarizing. This paper studies optimal monetary policy in a multisector economy in which firms are subject to sector-specific productivity shocks and pay menu costs to adjust their prices. We show analytically that stabilizing nominal marginal costs in un-shocked sectors is optimal for sufficiently large shocks, which results in countercyclical inflation. Even in a rich quantitative version of the model, targeting nominal wages is strictly preferable to conventional inflation targeting.

Our findings underscore the importance of allowing sector-specific shocks to transmit directly into aggregate inflation – a recommendation aligning with recent central banking perspectives that advocate "looking through" sectoral shocks (Powell 2023; Brainard 2022; Schnabel 2022). Practical historical examples, such as central bank responses to oil price shocks, illustrate the inefficiency of rigidly pursuing inflation stabilization objectives in the presence of significant sectoral disturbances.

Practical implementation. A full analysis of practical considerations for implementing optimal policy is beyond the scope of this paper and is a topic ripe for future research. One important question for policymakers may be the choice of which empirical measure of nominal wages to track in order to best track nominal marginal costs. A similar issue arises for inflation targeting, where policymakers and analysts frequently debate the relevance of "headline" versus "core" inflation; or debate the use of a consumer price index versus personal consumption expenditures; or consider "trimming" components of any of these price indices. A second question may be the role of revisions in nominal wage statistics, although once again there is a similar issue for tracking inflation since inflation revisions are often quite sizeable (Audoly et al. 2023). Third and more generally, optimal policy under menu costs may be affected by information constraints facing the central bank. This is plausibly important: for example, a lack of knowledge of the true level of the output gap and the natural rate of interest have been an important challenge for monetary policy historically (Orphanides 2003; Gorodnichenko and Shapiro 2007), as emphasized conceptually by Friedman (1968).

Future work. The conclusion that optimal monetary policy in response to sectoral shocks should result in countercyclical inflation resonates with the results of other studies in the broader optimal monetary policy literature away from Calvo sticky prices, as discussed in the introduction (Sheedy 2014; Angeletos and La'O 2020; Selgin 1997).[29] Integrating these varied approaches into a unified theory of optimal monetary policy is an open question for future research.

References

Adam, Klaus, and Henning Weber. 2023. "Estimating the optimal inflation target from trends in relative prices." *American Economic Journal: Macroeconomics*.

Alvarez, Fernando, Francesco Lippi, and Luigi Paciello. 2011. "Optimal price setting with observation and menu costs." *The Quarterly Journal of Economics*, 126(4): 1909–1960.

Alvarez, Fernando, Martin Beraja, Martin Gonzalez-Rozada, and Pablo Andrés Neumeyer. 2019. "From hyperinflation to stable prices: Argentina's evidence on menu cost models." *The Quarterly Journal of Economics*, 134(1): 451–505.

Anderson, Eric T, and Duncan I Simester. 2010. "Price stickiness and customer antagonism." *The Quarterly Journal of Economics*, 125(2): 729–765.

Angeletos, George-Marios, and Jennifer La'O. 2020. "Optimal monetary policy with informational frictions." *Journal of Political Economy*, 128(3): 1027–1064.

Aoki, Kosuke. 2001. "Optimal monetary policy responses to relative-price changes." *Journal of Monetary Economics*, 48(1): 55–80.

Auclert, Adrien, Bence Bardóczy, Matthew Rognlie, and Ludwig Straub. 2021. "Using the sequence-space Jacobian to solve and estimate heterogeneous-agent models." *Econometrica*, 89(5): 2375–2408.

Auclert, Adrien, Matthew Rognlie, and Ludwig Straub. 2018. "The Intertemporal Keynesian Cross." *National Bureau of Economic Research*, , (August): 1–58.

Auclert, Adrien, Rodolfo Rigato, Ludwig Straub, and Matthew Rognlie. 2023. "New Pricing Models, Same Old Phillips Curve?" *The Quarterly Journal of Economics*, 138(4): qjad041.

---

[29]More generally, the optimality of countercyclical inflation is also discussed in the literature on nominal income targeting. For informal such discussion beyond the works already cited, see Sumner (2012), Beckworth (2019), Binder (2020), and Hall and Mankiw (1994).

Audoly, Richard, Martin Almuzara, Richard K Crump, Davide Melcangi, and Roshie Xing. 2023. "How Large Are Inflation Revisions? The Difficulty of Monitoring Prices in Real Time." *The Difficulty of Monitoring Prices in Real Time (September 7, 2023). Liberty Street Economics.*

Ball, Laurence. 1987. "Externalities from Contract Length." *The American Economic Review,* 77(4): 615–629.

Ball, Laurence, and David Romer. 1989*a*. "Are Prices too Sticky?" *Quarterly Journal of Economics,* 104(3): 507–524.

Ball, Laurence, and David Romer. 1989*b*. "The equilibrium and optimal timing of price changes." *Review of Economic Studies,* 56(2): 179–198.

Ball, Laurence, and David Romer. 1991. "Sticky Prices as Coordination Failure." *The American Economic Review,* 81(3).

Barro, Robert J. 1972. "A theory of monopolistic price adjustment." *Review of Economic Studies,* 39(1): 17–26.

Basu, Susanto. 1995. "Intermediate Goods and Business Cycles: Implications for Productivity and Welfare." *American Economic Review,* 85: 512.

Beckworth, David. 2019. "Facts, Fears, and Functionality of NGDP Level Targeting: A Guide to a Popular Framework for Monetary Policy."

Benigno, Pierpaolo. 2004. "Optimal monetary policy in a currency area." *Journal of International Economics,* 63(2): 293–320.

Binder, Carola. 2020. "NGDP targeting and the public." *Cato Journal,* 40(2): 321–342.

Blanco, Andres. 2021. "Optimal inflation target in an economy with menu costs and a zero lower bound." *American Economic Journal: Macroeconomics,* 13(3): 108–41.

Brainard, Lael. 2022. "What Can We Learn from the Pandemic and the War about Supply Shocks, Inflation, and Monetary Policy?: At the 21st BIS Annual Conference Central Banking after the Pandemic: Challenges Ahead, Bank for International Settlements, Basel, Switzerland November 28th 2022."

Bullard, James, and Riccardo DiCecio. 2019. "Optimal monetary policy for the masses." *FRB St. Louis Working Paper,* , (2019-9).

Bullard, James, Riccardo DiCecio, Aarti Singh, and Jacek Suda. 2023. "Optimal Macroeconomic Policies in a Heterogeneous World."

Caballero, Ricardo J, and Eduardo MRA Engel. 2007. "Price stickiness in Ss models: New interpretations of old results." *Journal of Monetary Economics*, 54: 100–121.

Calabresi, Guido. 1970. *The Cost of Accidents.*

Caplin, Andrew, and John Leahy. 1994. "Business as usual, market crashes, and wisdom after the fact." *The American economic review*, 548–565.

Caplin, Andrew, and John Leahy. 2010. "Economic Theory and the World of Practice: A Celebration of the (S, s) Model." *Journal of Economic Perspectives*, 24(1): 183–202.

Caplin, Andrew S, and Daniel F Spulber. 1987. "Menu costs and the neutrality of money." *The Quarterly Journal of Economics*, 102(4): 703–725.

Carvalho, Carlos, and Oleksiy Kryvtsov. 2021. "Price selection." *Journal of Monetary Economics*, 122: 56–75.

Cavallo, Alberto. 2018. "Scraped data and sticky prices." *Review of Economics and Statistics*, 100(1): 105–119.

Cavallo, Alberto, and Roberto Rigobon. 2016. "The billion prices project: Using online prices for measurement and research." *Journal of Economic Perspectives*, 30(2): 151–178.

Dutta, Shantanu, Mark Bergen, Daniel Levy, and Robert Venable. 1999. "Menu costs, posted prices, and multiproduct retailers." *Journal of Money, Credit, and Banking*, 683–703.

Eggertsson, Gauti, and Michael Woodford. 2003. "The Zero Bound On Interest Rates and Optimal Monetary Policy." *Brookings Papers on Economic Activity*, 34.

Erceg, Christopher J., and Andrew T. Levin. 2006. "Optimal Monetary Policy with Durable Consumption Goods." *Journal of Monetary Economics*, 53(3): 631–653.

Erceg, Christopher J, Dale W Henderson, and Andrew T Levin. 2000. "Optimal monetary policy with staggered wage and price contracts." *Journal of Monetary Economics*, 46(2): 281–313.

Eusepi, Stefano, Bart Hobijn, and Andrea Tambalotti. 2011. "CONDI: A cost-of-nominal-distortions index." *American Economic Journal: Macroeconomics*, 3(3): 53–91.

Eyster, Erik, Kristóf Madarász, and Pascal Michaillat. 2021. "Pricing under Fairness Concerns." *Journal of the European Economic Association*, 19(3): 1853–1898.

Friedman, Milton. 1968. "The Role of Monetary Policy." *The American Economic Review*, 58(1): 1–17.

Gali, Jordi. 2008. *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework and Its Applications.*

Garin, Julio, Michael J Pries, and Eric R Sims. 2018. "The relative importance of aggregate and sectoral shocks and the changing nature of economic fluctuations." *American Economic Journal: Macroeconomics*, 10(1): 119–148.

Gautier, Erwan, and Hervé Le Bihan. 2022. "Shocks versus Menu Costs: Patterns of Price Rigidity in an Estimated Multisector Menu-Cost Model." *Review of Economics and Statistics*, 104(4): 668–685.

Gautier, Erwan, Cristina Conflitti, Riemer P Faber, Brian Fabo, Ludmila Fadejeva, Valentin Jouvanceau, Jan-Oliver Menz, Teresa Messner, Pavlos Petroulas, Pau Roldan-Blanco, et al. 2022. "New facts on consumer price rigidity in the euro area."

Gertler, Mark, and John Leahy. 2008. "A Phillips curve with an Ss foundation." *Journal of Political Economy*, 116(3): 533–572.

Golosov, Mikhail, and Robert E Lucas. 2007. "Menu costs and Phillips curves." *Journal of Political Economy*, 115(2): 171–199.

Gorodnichenko, Yuriy. 2008. "Endogenous information, menu costs and inflation persistence." National Bureau of Economic Research.

Gorodnichenko, Yuriy, and Matthew D Shapiro. 2007. "Monetary policy when potential output is uncertain: Understanding the growth gamble of the 1990s." *Journal of Monetary Economics*, 54(4): 1132–1162.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory W Huffman. 1988. "Investment, Capacity Utilization, and the Real Business Cycle." *The American Economic Review*, 78(3): 402–417.

Guerreiro, Joao, Jonathon Hazell, Chen Lian, and Christina Patterson. 2024. "Why Do Workers Dislike Inflation? Wage Erosion and Conflict Costs." National Bureau of Economic Research.

Guerrieri, Veronica, Guido Lorenzoni, Ludwig Straub, and Ivan Werning. 2021. "Monetary Policy in Times of Structural Reallocation." *Proceedings of the 2021 Jackson Hole Symposium*.

Hall, Robert E, and N Gregory Mankiw. 1994. "Nominal income targeting." In *Monetary policy*. 71–94. The University of Chicago Press.

Huang, Kevin XD, and Zheng Liu. 2005. "Inflation targeting: What inflation rate to target?" *Journal of Monetary Economics*, 52(3).

Karadi, Peter, Anton Nakov, Galo Nuño, Ernesto Pastén, and Dominik Thaler. 2025. "Strike while the Iron is Hot–Optimal Monetary Policy under State-Dependent Pricing." Working Paper Series.

Karadi, Peter, Raphael Schoenle, and Jesse Wursten. 2022. "Price selection in the microdata." Tech. rep., Mimeo. Oct. 10.

Klenow, Peter J, and Oleksiy Kryvtsov. 2008. "State-dependent or time-dependent pricing: Does it matter for recent US inflation?" *The Quarterly Journal of Economics*, 123(3): 863–904.

Koenig, Evan F. 2013. "Like a good neighbor: Monetary policy, financial stability, and the distribution of risk." *International Journal of Central Banking*.

Kreamer, Jonathan. 2022. "Sectoral Heterogeneity and Monetary Policy." *American Economic Journal: Macroeconomics*, 14(2): 123–159.

Levy, Daniel, Mark Bergen, Shantanu Dutta, and Robert Venable. 1997. "The magnitude of menu costs: direct evidence from large US supermarket chains." *The Quarterly Journal of Economics*, 112(3): 791–824.

Maćkowiak, Bartosz, Filip Matějka, and Mirko Wiederholt. 2023. "Rational inattention: A review." *Journal of Economic Literature*, 61(1): 226–273.

Mankiw, N. Gregory. 1985. "Small Menu Costs and Large Business Cycles: A Macroeconomic Model of Monopoly." *Quarterly Journal of Economics*, 100(2): 529–537.

Mankiw, N. Gregory, and Ricardo Reis. 2003. "What measure of inflation should a central bank target?" *Journal of Monetary Economics*.

Midrigan, Virgiliu. 2011. "Menu costs, multiproduct firms, and aggregate fluctuations." *Econometrica*, 79(4): 1139–1180.

Nakamura, Emi, and Jón Steinsson. 2008. "Five facts about prices: A reevaluation of menu cost models." *The Quarterly Journal of Economics*, 123(4): 1415–1464.

Nakamura, Emi, and Jon Steinsson. 2010. "Monetary non-neutrality in a multisector menu cost model." *The Quarterly Journal of Economics*, 125(3): 961–1013.

Nakamura, Emi, Jón Steinsson, Patrick Sun, and Daniel Villar. 2018. "The elusive costs of inflation: Price dispersion during the US great inflation." *The Quarterly Journal of Economics*, 133(4): 1933–1980.

Nakov, Anton, and Carlos Thomas. 2014. "Optimal monetary policy with state-dependent pricing." *International Journal of Central Banking*, 10(3): 49–94.

Nisticò, Salvatore. 2007. "The welfare loss from unstable inflation." *Economics Letters*, 96(1): 51–57.

Orphanides, Athanasios. 2003. "Historical monetary policy analysis and the Taylor rule." *Journal of Monetary Economics*, 50(5): 983–1022.

Poole, William. 1970. "Optimal choice of monetary policy instruments in a simple stochastic macro model." *Quarterly Journal of Economics.*

Powell, Jerome. 2023. "Opening Remarks, at "Monetary Policy Challenges in a Global Economy"."

Rotemberg, Julio J. 1982. "Sticky prices in the United States." *Journal of Political Economy*, 90(6): 1187–1211.

Rubbo, Elisa. 2023. "Networks, Phillips curves, and monetary policy." *Econometrica*, 91(4): 1417–1455.

Schnabel, Isabel. 2022. "Looking through Higher Energy Prices? Monetary Policy and the Green Transition."

Selgin, George. 1997. *Less Than Zero: The Case for a Falling Price Level in a Growing Economy.* Institute for Economic Affairs.

Sheedy, Kevin D. 2014. "Debt and incomplete financial markets: A case for nominal GDP targeting." *Brookings Papers on Economic Activity*, 2014(1): 301–373.

Sheshinki, Eytan, and Yoram Weiss. 1977. "Inflation and Costs of Price Adjustment." *The Review of Economic Studies*, 44(2): 287–303.

Sumner, Scott. 2012. "The Case for Nominal GDP Targeting." *Mercatus Center working paper*.

Werning, Ivan. 2011. "Managing a liquidity trap: Monetary and fiscal policy." National Bureau of Economic Research.

Werning, Ivan. 2014. "Comment: Debt and Incomplete Financial Markets." *Brookings Papers on Economic Activity*, 368–372.

Wolman, Alexander L. 2011. "The optimal rate of inflation with trending relative prices." *Journal of Money, Credit and Banking*, 43(2-3): 355–384.

Woodford, Michael. 1998. "Doing without Money: Controlling Inflation in a Post-Monetary World." *Review of Economic Dynamics*, 1(1): 173–219.

Woodford, Michael. 2003. "Interest and prices: Foundations of a theory of monetary policy."

Woodford, Michael. 2012. "Methods of policy accommodation at the interest-rate lower bound."

Yun, Tack. 1996. "Nominal price rigidity, money supply endogeneity, and business cycles." *Journal of Monetary Economics*, 37(2): 345–370.

Zbaracki, Mark J, Mark Ritson, Daniel Levy, Shantanu Dutta, and Mark Bergen. 2004. "Managerial and customer costs of price adjustment: direct evidence from industrial markets." *Review of Economics and Statistics*, 86(2): 514–533.

A Additional proofs

A.1 Proof of lemma 1

Proof. Equation (12) showed that a firm j in sector i with inherited price p_i^{old} adjusts if and only if:

$$\left(\frac{W}{A_i}\right)^{1-\eta} p_i^{\eta} y_i \left[\frac{1}{\eta}\right] - W\psi > \left(p_i^{\text{old}}\right)^{1-\eta} p_i^{\eta} y_i \left[1 - \frac{W/A_i}{p_i^{\text{old}}} \cdot \frac{\eta - 1}{\eta}\right]$$

Define:

$$f(W, A_i) \equiv \left(\frac{W}{A_i}\right)^{1-\eta} p_i^{\eta} y_i \left[\frac{1}{\eta}\right] - W\psi - \left(p_i^{\text{old}}\right)^{1-\eta} p_i^{\eta} y_i \left[1 - \frac{W/A_i}{p_i^{\text{old}}} \cdot \frac{\eta - 1}{\eta}\right] \qquad (53)$$

The firm will adjust iff $f(W, A_i) \geq 0$.

Observe first that for the locus of (W, A_i) such that $W/A_i = p_i^{\text{old}}$, it is the case that $f(W, A_i) = -W\psi < 0$ and the firm will not adjust. That is, this locus is a subset of the inaction region $\Lambda \equiv \{(W, A_i) | f(W, A_i) < 0\}$. Thus Λ is nonempty.

In A_i space. Observe that

$$\frac{\partial f}{\partial A_i} = p_i^{\eta} y_i W (A_i^{-2}) \left(\frac{\eta - 1}{\eta}\right) \left[\left(\frac{W}{A_i}\right)^{-\eta} - (p_i^{\text{old}})^{-\eta}\right]$$

This is positive iff $W/A_i < p_i^{\text{old}}$. Additionally, $\lim_{A_i \to 0} f(\cdot, A_i) = \lim_{A_i \to \infty} f(\cdot, A_i) = \infty$ and $f(\cdot, A_i)$ is continuous in A_i on $(0, \infty)$.

Now consider any fixed W^0 such that there exists some A_i^0 with $f(W^0, A_i^0) < 0$. Then by the intermediate value theorem there exists an inaction interval $(\underline{\lambda}, \overline{\lambda})$ around W^0 such that $f(W^0, \underline{\lambda}) = f(W^0, \overline{\lambda}) = 0$, and $f(W^0, A_i) < 0$ iff $A_i \in (\underline{\lambda}, \overline{\lambda})$. To see that $\overline{\lambda}$ is increasing in ψ and $\underline{\lambda}$ is decreasing in ψ, observe that increasing ψ shifts the entire $f(x)$ curve down, i.e. $\frac{\partial f}{\partial \psi} < 0$.

If for a fixed W^0 there is no A_i with $f(W, A_i) < 0$, then by construction there is no point in Λ along W^0.

In W space. Similarly, observe that

$$\frac{\partial f}{\partial W} = p_i^{\eta} y_i A_i^{-1} \left(\frac{\eta - 1}{\eta}\right) \left[(p_i^{\text{old}})^{-\eta} - \left(\frac{W}{A_i}\right)^{-\eta}\right] - \psi$$

This is zeroed for the locus of (W, A_i) such that

$$\left(\frac{W}{A_i}\right)^{-\eta} = (p_i^{\text{old}})^{-\eta} - \psi p_i^{-\eta} y_i^{-1} A_i \left(\frac{\eta - 1}{\eta}\right)^{-1} \equiv \zeta^{-\eta}$$

Observe that $f_1 < 0$ iff $W/A_i < \zeta$. Additionally, $\lim_{W \to 0} f(W, \cdot) = \infty$.[30] Additionally, $f(W, \cdot)$ is continuous in W on $(0, \infty)$. Thus, as above, consider any fixed A_i^0 such that there exists some W^0 with $f(W^0, A_i^0) < 0$. By the intermediate value theorem there exists (abusing notation) an inaction interval $(\underline{\lambda}, \overline{\lambda})$ around A_i^0 such that $f(\underline{\lambda}, A_i^0) = f(\overline{\lambda}, A_i^0) = 0$, and $f(W, A_i^0) < 0$ iff $W \in (\underline{\lambda}, \overline{\lambda})$, where $\overline{\lambda}$ is potentially infinite. To see that $\overline{\lambda}$ is increasing in ψ and $\underline{\lambda}$ is decreasing in ψ, observe that increasing ψ shifts the entire $f(x)$ curve down, i.e. $\frac{\partial f}{\partial \psi} < 0$. □

---

[30]The second limit comes from using L'Hopital's rule, together with the natural parameter restriction that $\psi < \frac{1}{s\eta}$. Without this maximum bound on ψ, firms would *always* earn negative profits after adjusting – i.e., firms would *never* adjust.

A.2 Formal statement of planner's problem

Recall we derived that equilibrium welfare in each of the four regimes as a (potentially constant) function of the social planner's choice of the money supply:

$$\mathbb{W}_{\text{all adjust}} = \ln\left(\frac{\gamma^{1/S}}{S}\right) - [1 + S\psi]$$

$$\mathbb{W}_{\text{only 1 adjusts}}(M) = \ln\left(\frac{\gamma^{\frac{1}{S}}}{S}M^{\frac{S-1}{S}}\right) - \left[\frac{1}{S} + (S-1)\frac{M}{S} + \psi\right]$$

$$\mathbb{W}_{\text{only } k \text{ adjust}}(M) = \ln\left(\frac{1}{S}M^{1/S}\right) - \left[\frac{S-1}{S} + \frac{1}{S}\frac{M}{S} + \frac{S-1}{S}\psi\right]$$

$$\mathbb{W}_{\text{none adjust}}(M) = \ln\left(\frac{M}{S}\right) - \left[\frac{1}{\gamma}\frac{M}{S} + (S-1)\frac{M}{S}\right]$$

Constrained planner's problem. We define the constrained planner as the planner who chooses M in each regime to maximize welfare, *constrained* by the fact that the choice of M must be incentive compatible with whether various sectors actually adjust or not:

$$M_{\text{only 1 adjusts}}^{*,\text{ constrained}} \equiv \arg\max_{M} \mathbb{W}_{\text{only 1 adjusts}}(M) \tag{54}$$
$$\text{s.t. } f(M,\gamma) \geq 0 \text{ and } f(M,1) \leq 0$$

$$M_{\text{only } k \text{ adjust}}^{*,\text{ constrained}} \equiv \arg\max_{M} \mathbb{W}_{\text{only } k \text{ adjust}}(M) \tag{55}$$
$$\text{s.t. } f(M,\gamma) \leq 0 \text{ and } f(M,1) \geq 0$$

$$M_{\text{none adjust}}^{*,\text{ constrained}} \equiv \arg\max_{M} \mathbb{W}_{\text{none adjust}}(M) \tag{56}$$
$$\text{s.t. } f(M,\gamma) \leq 0 \text{ and } f(M,1) \leq 0$$

where $f(M, A_i)$ refers to the function defined in (29) which is positive if and only if firms in sector i want to adjust. This defines, for example, $M_{\text{only 1 adjusts}}^{*,\text{ constrained}}$ as the level of money supply which maximizes welfare in equilibrium when only sector 1 adjusts $\mathbb{W}_{\text{only 1 adjusts}}(M)$, *subject to the constraint that* it is indeed incentive-compatible for sector-1 firms to adjust, $f(M,\gamma) \geq 0$, and incentive-compatible for firms in sectors k to not adjust, $f(M,1) \leq 0$. Denote the associated constrained-optimal levels of welfare in each regime as:

$$\mathbb{W}_{\text{only 1 adjusts}}^{*,\text{ constrained}} = \mathbb{W}_{\text{only 1 adjusts}}\left(M_{\text{only 1 adjusts}}^{*,\text{ constrained}}\right)$$

$$W_{\text{only } k \text{ adjust}}^{*,\,\text{constrained}} = W_{\text{only } k \text{ adjust}}\left(M_{\text{only } k \text{ adjust}}^{*,\,\text{constrained}}\right)$$

$$W_{\text{none adjust}}^{*,\,\text{constrained}} = W_{\text{none adjust}}\left(M_{\text{none adjust}}^{*,\,\text{constrained}}\right)$$

The constrained social planner's problem is then to select among these, or to implement the regime where all adjust (in which case the choice of M is irrelevant, as long as it is incentive-compatible):

$$\max\left\{W_{\text{only 1 adjusts}}^{*,\,\text{constrained}}, W_{\text{only } k \text{ adjust}}^{*,\,\text{constrained}}, W_{\text{none adjust}}^{*,\,\text{constrained}}, W_{\text{all adjust}}\right\} \tag{57}$$

which she implements with the associated incentive-compatible choice for the money supply.

Unconstrained social planner's problem. In the body of the paper and in this subsection, we endow the planner with the instrument of subsidizing menu costs, so that the constraints on (54), (55), and (56) never bind. Because taxation is lump sum and wholly non-distortionary, subsidies to offset the menu cost are equivalent to endowing the planner with the power to change prices directly (but, if doing so, still incurring a menu cost for affected firms). The unconstrained social planner's problem is thus the same as the constrained planner's problem, but without any of the implementability constraints.

$$M_{\text{only 1 adjusts}}^{*} \equiv \arg\max_{M} W_{\text{only 1 adjusts}}(M) \tag{58}$$

$$M_{\text{only } k \text{ adjust}}^{*} \equiv \arg\max_{M} W_{\text{only } k \text{ adjust}}(M) \tag{59}$$

$$M_{\text{none adjust}}^{*} \equiv \arg\max_{M} W_{\text{none adjust}}(M) \tag{60}$$

Since the objective functions in all of these arg maxes are strictly concave, the solution is found from the first order condition, as presented in the text. We denoted the associated unconstrained-optimal levels of welfare in each regime in equations (18), (19), (20) as:

$$W_{\text{only 1 adjusts}}^{*} = W_{\text{only 1 adjusts}}\left(M_{\text{only 1 adjusts}}^{*}\right)$$

$$W_{\text{only } k \text{ adjust}}^{*} = W_{\text{only } k \text{ adjust}}\left(M_{\text{only } k \text{ adjust}}^{*}\right)$$

$$W_{\text{none adjust}}^{*} = W_{\text{none adjust}}\left(M_{\text{none adjust}}^{*}\right)$$

The constrained social planner's problem is then to select among these, or to imple-

ment the regime where all adjust (in which case the choice of M is irrelevant):

$$\max \left\{ \mathbb{W}^*_{\text{only 1 adjusts}}, \mathbb{W}^*_{\text{only } k \text{ adjust}}, \mathbb{W}^*_{\text{none adjust}}, \mathbb{W}_{\text{all adjust}} \right\} \tag{61}$$

It is this maximization problem that produces lemma 2 and lemma 3, which in turn produce proposition 1. $\qquad\square$

B Adjustment externalities

In this section, we work with a slightly modified version of the baseline model, where menu costs are modeled as a utility penalty rather than as a labor cost. This highlights the way in which the results do not depend on how menu costs are modeled, and also facilitates an analysis of the role of adjustment externalities.

B.1 Model setup

The final goods producer and sectoral goods producer are exactly the same as the baseline model.

Intermediate goods producers. The intermediate goods producers again are a unit mass of monopolistically competitive firms in each sector with linear technology and productivity that is common to the sector. They again face a menu cost if adjusting prices. Here, unlike the baseline model, the adjustment cost is not ψ units of extra labor, but a penalty $(1 - \psi)$ that scales down the firm manager's objective function (but not profits). Firm i in sector j faces the following maximization program:

$$
\max_{p_i(j)} D_i(j) \left(1 - \psi \chi_i(j)\right)
$$
$$
\text{s.t. } D_i(j) = p_i(j) y_i(j) - W n_i(j)(1 - \tau)
$$
$$
\chi_i(j) = \begin{cases} 1 & \text{if } p_i(j) \neq p_i^{\text{old}} \\ 0 & \text{else} \end{cases}
$$
$$
y_i(j) = y_i \left(\frac{p_i(j)}{p_i} \right)^{-\eta}
$$
$$
y_i(j) = A_i n_i(j)
$$

This menu cost is a utility penalty that is passed on to households, but does not affect physical profits. As before, all firms within a sector face the same problem, and we drop the (j) notation when the context is clear.

Households. The representative household is precisely as in the baseline model, except that the utility function (1) is modified to be:

$$
\mathbb{W} = \ln C - N + \ln \left(\frac{M}{P} \right) - \psi \sum_i \chi_i
$$

The household has the same preferences over consumption, labor, and real balances; but now is directly penalized in terms of welfare when firms adjust prices. The benefit of this modeling technique is that it turns off the income effects caused by menu costs, as discussed in section 5.1, and is a technique that has been used by e.g. Auclert, Rognlie and Straub (2018) or Guerrieri et al. (2021).

B.2 Shock and equilibrium

We run the same exercise, shocking the productivity of sector 1 from $A_1 = 1$ to $A_1 = \gamma > 1$. The equilibrium allocations in the four regimes 3.1 is *exactly* the same as in the body of the paper, except that the level of aggregate labor in each of the four regimes is no longer affected by menu costs. The equilibrium level of welfare in each of the four regimes as a function of the choice of money supply is:

$$\mathbb{W}_{\text{flex}} = \ln\left(\frac{\gamma^{1/S}}{S}\right) - 1$$

$$\mathbb{W}_{\text{all adjust}} = \ln\left(\frac{\gamma^{1/S}}{S}\right) - 1$$

$$\mathbb{W}_{\text{only 1 adjusts}}(M) = \ln\left(\frac{\gamma^{1/S}}{S} M^{\frac{S-1}{S}}\right) - \frac{1}{S}[1 + M(S-1)] - \psi$$

$$\mathbb{W}_{\text{only k adjust}}(M) = \ln\left(\frac{1}{S} M^{\frac{1}{S}}\right) - \frac{1}{S}\left[S - 1 + \frac{M}{\gamma}\right] - (S-1)\psi$$

$$\mathbb{W}_{\text{none adjust}}(M) = \ln\left(\frac{M}{S}\right) - \frac{M}{S}\left[S - 1 + \frac{1}{\gamma}\right]$$

B.3 Adjustment decision

The firm compares its objective function under price adjustment versus under the inherited price. The adjustment condition can be simplified to be written as: adjust if and only if

$$\frac{1}{\eta}(1 - \psi) > \left[\frac{W/A_i}{p_i^{\text{old}}}\right]^{\eta}\left(\left[\frac{W/A_i}{p_i^{\text{old}}}\right]^{-1} - \frac{\eta - 1}{\eta}\right)$$

For additional analytical tractability, we make the following assumption in this section:

Assumption 1. The elasticity of substitution is $\eta = 2$.

This assumption allows for a closed form solution to the inaction region, using the quadratic formula: do not adjust if and only if

$$\frac{W}{A_i} \in \left(p_i^{\text{old}}(1 - \sqrt{\psi}), p_i^{\text{old}}(1 + \sqrt{\psi}) \right) \tag{62}$$

Clearly this has the same properties as the Λ inaction region described in lemma 1.

When starting from the steady state where p_i^{old} for all sectors i, and using the equilibrium $W = M$ condition, then we have the following. The inaction region for sector 1 is

$$M \in (\gamma(1 - \sqrt{\psi}), \gamma(1 + \sqrt{\psi}))$$

The inaction region for sectors k is

$$M \in (1 - \sqrt{\psi}, 1 + \sqrt{\psi})$$

B.4   The planner's problem

The planner's problem – importantly, without the ability to subsidize menu costs and so denoted "constrained" – written in full is:

$$\max_{\substack{\text{all adjust, only 1 adjusts} \\ \text{only } k \text{ adjust, none adjust}}} \left\{ \mathbb{W}_{\text{all adjust}}, \mathbb{W}_{\text{only 1 adjusts}}^{*,\text{constrained}}, \mathbb{W}_{\text{only } k \text{ adjust}}^{*,\text{constrained}}, \mathbb{W}_{\text{none adjust}}^{*,\text{constrained}} \right\} \tag{63}$$

$$\text{s.t.}$$

$$\mathbb{W}_{\text{all adjust}} = \left\{ \ln\left(\frac{\gamma^{1/S}}{S} \right) - 1 \right\}$$

$$\mathbb{W}_{\text{only 1 adjusts}}^{*,\text{constrained}} = \left\{ \begin{matrix} \max_{M} \; \ln\left(\frac{\gamma^{1/S}}{S} M^{\frac{S-1}{S}} \right) - \frac{1}{S}[1 + M(S-1)] - \psi \\ \text{s.t. } M \in (1 - \sqrt{\psi}, 1 + \sqrt{\psi}) \\ M \notin (\gamma(1 - \sqrt{\psi}), \gamma(1 + \sqrt{\psi})) \end{matrix} \right\}$$

$$\mathbb{W}_{\text{only } k \text{ adjust}}^{*,\text{constrained}} = \left\{ \begin{matrix} \max_{M} \; \ln\left(\frac{1}{S} M^{\frac{1}{S}} \right) - \frac{1}{S}\left[S - 1 + \frac{M}{\gamma} \right] - (S-1)\psi \\ \text{s.t. } M \notin (1 - \sqrt{\psi}, 1 + \sqrt{\psi}) \\ M \in (\gamma(1 - \sqrt{\psi}), \gamma(1 + \sqrt{\psi})) \end{matrix} \right\}$$

$$\mathbb{W}_{\text{none adjust}}^{*,\text{constrained}} = \left\{ \begin{matrix} \max_{M} \; \ln\left(\frac{M}{S} \right) - \frac{M}{S}\left[S - 1 + \frac{1}{\gamma} \right] \\ \text{s.t. } M \in (1 - \sqrt{\psi}, 1 + \sqrt{\psi}) \\ M \in (\gamma(1 - \sqrt{\psi}), \gamma(1 + \sqrt{\psi})) \end{matrix} \right\}$$

B.5 Interior optima

The interior optima for each regime, found from the first order conditions, are the same as the baseline model:

$$M^{\text{interior}}_{\text{only 1 adjusts}} = 1$$

$$M^{\text{interior}}_{\text{only } k \text{ adjust}} = \gamma$$

$$M^{\text{interior}}_{\text{none adjust}} = \frac{S}{S - 1 + 1/\gamma}$$

B.6 Only sector 1 adjusts: The possibility of *positive* adjustment externalities

Suppose the unconstrained social planner – i.e., one who could subsidize menu costs and ignore the implementability constraints – would want to implement the regime where only sector 1 adjusts, and she therefore wants to set $M = 1$. We now examine whether this is incentive compatible: does it result in sector-k firms being within their inaction region and sector-1 firms being outside it?

First observe that $M = 1$ indeed ensures that sector-k firms are in their inaction region, since $M = 1 \in (1 - \sqrt{\psi}, 1 + \sqrt{\psi})$ always.

However, it is possible that $M = 1$ could leave sector-1 firms inside their inaction region, if the following condition holds:

$$\gamma < \frac{1}{1 - \sqrt{\psi}} \equiv \gamma_1 \tag{64}$$

As an existence proof, it is possible to come up with numerical examples for parameters satisfying the above where it would be, in fact, socially optimal to implement this regime if there were no implementability constraints. When this is the case, then the best the central bank can do within this regime is to set $M = \gamma(1 - \sqrt{\psi})$. This is a case of *positive* adjustment externalities: the social planner would prefer that sector 1 adjusts its prices, even though it is individually rational to not do so.

B.7 No sectors adjust: The possibility of *negative* adjustment externalities

Now suppose the unconstrained social planner would prefer that no sector adjusts (i.e. $\gamma < \bar{\gamma}$). The interior optimum level of the money supply, as previously noted, would

be $M^{\text{interior}}_{\text{none adjust}} = \frac{S}{S-1+1/\gamma}$. Is this incentive-compatible?

To be incentive-compatible requires that both $\frac{S}{S-1+1/\gamma} > \gamma(1-\sqrt{\psi})$ and $\frac{S}{S-1+1/\gamma} < 1 + \sqrt{\psi}$. Thus, there is a *negative* adjustment externality – where its privately optimal for firms in a sector to adjust even when its not socially optimal to do so – if either:

$$\gamma < \frac{1 + \frac{1}{S-1}\sqrt{\psi}}{1 - \sqrt{\psi}} \equiv \gamma_2 \tag{65}$$

or

$$\gamma > \frac{1 + \sqrt{\psi}}{S - (S-1)(1+\sqrt{\psi})} \equiv \gamma_3 \tag{66}$$

As an existence proof, it is possible to come up with numerical examples for parameters satisfying either of the above where it would be, in fact, socially optimal to implement this regime if there were no implementability constraints. When this is the case, then the best the central bank can do within this regime is to set M at the respective boundary.

B.8 Summarizing the possibilities for welfare

A similar analysis the above can be done for the case when only sectors k adjust, where a constraint will bind if $\gamma > \gamma_4 \equiv 1 + \sqrt{\psi}$. We summarize the results from above and this additional case in the following:

$$\mathbb{W}_{\text{all adjust}} = \mathbb{W}_{\text{flex}} - S\psi$$

$$\mathbb{W}^{*,\text{constrained}}_{\text{only 1 adjusts}} = \begin{cases} \mathbb{W}_{\text{flex}} - \psi & \text{if } \gamma \geq \gamma_1 \\ \ln\left(\frac{\gamma^{1/S}}{S}\gamma_1^{\frac{S-1}{S}}\right) - \frac{1}{S}\left[1 + \gamma_1(S-1)\right] - \psi & \text{else} \end{cases}$$

$$\mathbb{W}^{*,\text{constrained}}_{\text{only } k \text{ adjust}} = \begin{cases} \mathbb{W}_{\text{flex}} - (S-1)\psi & \text{if } \gamma \leq \gamma_4 \\ \ln\left(\frac{1}{S}\gamma_4^{1/S}\right) - \frac{1}{S}\left[S - 1 + \frac{\gamma_4}{\gamma}\right] - (S-1)\psi & \text{else} \end{cases}$$

$$\mathbb{W}^{*,\text{constrained}}_{\text{none adjust}} = \begin{cases} -\log\left[S - 1 + 1/\gamma\right] - 1 & \text{if } \gamma \in [\gamma_3, \gamma_2] \\ \ln\left(\frac{\gamma_2}{S}\right) - \frac{\gamma_2}{S}\left[S - 1 + \frac{1}{\gamma}\right] & \text{if } \gamma > \gamma_2 \\ \ln\left(\frac{\gamma_3}{S}\right) - \frac{\gamma_3}{S}\left[S - 1 + \frac{1}{\gamma}\right] & \text{if } \gamma < \gamma_3 \end{cases}$$

Optimal monetary policy considers which of these achieves the highest welfare, and

sets the money supply M to implement.

C Model with Segmented Labor Markets

In this appendix, we extend the baseline model to account for segmented labor markets, where each sector is populated by households that can only work in that sector. Therefore, wages, consumption, labor, and money holdings may differ across sectors. We show that the key result still holds: when one sector is hit by a shock, restricting price adjustments to one sector leads to higher welfare than allowing all sectors to adjust.

C.1 Household Problem

In the segmented labor market setting, workers are sector-specific, meaning that wages differ across sectors. The household in sector i derives utility from consumption C_i, sector-specific labor supply N_i, and real money balances M_i/P. The representative household in sector i maximizes:

$$W_i = \ln C_i - N_i + \ln \left(\frac{M_i}{P} \right) \tag{67}$$

subject to the budget constraint:

$$PC_i + M_i = W_i N_i + D + M_{-1} - T \tag{68}$$

where dividends D, transfers T, and the final good's price P are all common across sectors. The household chooses C_i, M_i, and N_i to maximize utility subject to the budget constraint. The first-order conditions result in the usual conditions

$$PC_i = M_i \tag{69}$$
$$W_i = M_i \tag{70}$$

Note, consumption, labor, and money supply are here sector-specific.

C.2 Firms

The production side remains identical to the baseline model.

C.3 Steady-State Equilibrium

In steady state, all sectors are symmetric, and the following conditions hold:

$$A_i = 1, \quad W_i = \frac{1}{S}, \quad M_i = \frac{1}{S}, \quad p_i = \frac{1}{S}, \quad P = 1, \tag{71}$$

$$C_i = \frac{1}{S}, \quad C = Y = 1, \quad y_i = n_i = 1. \tag{72}$$

C.4 Welfare Analysis

We now analyze welfare under two different monetary policy regimes:

1. **One Sector Adjustment:** The central bank sets M consistent with only sector 1 firms adjusting their prices in response to a productivity shock in sector 1.

2. **All Sectors Adjustment:** The central bank sets M consistent with all sectors adjusting their prices such that the aggregate price level remains constant.

One Sector Adjustment. Suppose the central bank sets the money supply to M^* so as to make all firms in sector 1 but no firm in sectors $k > 1$ change price. This implies that $M_k = W_k = \frac{M}{S}$ after the shock. And, in turn,

$$M_1 = M^* - \frac{S-1}{S} M$$

In this first regime $p_k = p_k^* = \frac{1}{S}$ which, by the efficiency conditions equals PC_k while $p_1 = \frac{W_1}{\gamma} = \frac{M_1}{\gamma} = \frac{PC_1}{\gamma}$. The aggregate price level is

$$P = S \prod_i p_i^{\frac{1}{S}} = (Sp_1)^{\frac{1}{S}}$$

Including the price level in the above expressions pins down consumption in each sector:

$$\begin{cases} C_1 = \frac{\gamma}{S^{\frac{1}{S}}} p_1^{1-\frac{1}{S}} \\ C_k = S^{-\frac{S+1}{S}} p_1^{-\frac{1}{S}} = \frac{1}{S} \frac{1}{S^{\frac{1}{S}}} p_1^{-\frac{1}{S}} \end{cases}$$

and total consumption is simply

$$C = (Sp_1)^{-\frac{1}{S}} \left(\gamma p_1 + \frac{S-1}{S} \right)$$

The aggregate resource constraint is $Y = C$. In turn, $PY = PC = \left(\gamma p_1 + \frac{S-1}{S}\right)$. Sectoral demand then becomes

$$y_i = \frac{1}{S}\frac{PY}{p_i} = \frac{1}{S}\frac{\gamma p_1 + \frac{S-1}{S}}{p_i}$$

For $k > 1$, $p_k = \frac{1}{S}$ and so $y_k = \left(\gamma p_1 + \frac{S-1}{S}\right)$, for sector 1, $y_1 = \frac{1}{S}\frac{\gamma p_1 + \frac{S-1}{S}}{p_1}$. In turn, labor demand is $n_k = y_k = \gamma p_1 + \frac{S-1}{S}$ and $n_1 = \frac{y_1}{\gamma} = \frac{1}{S}\frac{1}{\gamma}\frac{\gamma p_1 + \frac{S-1}{S}}{p_1}$. Labor supply in sector 1 is $N_1 = n_1 + \psi$, while in sectors k, just $N_k = n_k$. Rearranging the budget constraints of households in sector 1 and k, we have

$$PC_1 + M_1 - W_1 N_1 = D + M_{-1} - T$$

$$PC_k + M_k - W_k N_k = D + M_{-1} - T$$

The RHSs are identical and so must the LHSs. Substituting accordingly, gives

$$PC_1 + M_1 - W_1 N_1 = \gamma p_1 + \gamma p_1 + \gamma p_1 \cdot \left(\frac{1}{S}\frac{1}{\gamma}\frac{\gamma p_1 + \frac{S-1}{S}}{p_1} + \psi\right)$$

$$PC_k + M_k - W_k N_k = \frac{1}{S} + \frac{1}{S} + \frac{1}{S} \cdot \left(\gamma p_1 + \frac{S-1}{S}\right)$$

Solve for p_1 by denoting $x \equiv \gamma p_1$ and substituting in the previous two expressions and equate them

$$2x + x\left(\frac{1}{S}\frac{x + \frac{S-1}{S}}{x} + \psi\right) = \frac{2}{S} + \frac{x + \frac{S-1}{S}}{S}$$

which becomes

$$2x + \frac{x + \frac{S-1}{S}}{S} + \psi x = \frac{2}{S} + \frac{x + \frac{S-1}{S}}{S}$$

and so $(2 + \psi)x = \frac{2}{S} \Rightarrow x = \frac{2}{S(2+\psi)}$ which means that

$$p_1 = \frac{2}{S\gamma}\frac{1}{2 + \psi}$$

Note, if $\gamma = 1$ and $\psi = 0$, we get back to $p_1 = \frac{1}{S}$, as in steady state. With this price, we have that

$$P = \left(\frac{1}{\gamma} \cdot \frac{2}{2 + \psi}\right)^{\frac{1}{S}}$$

$$C_1 = \frac{\gamma^{\frac{1}{S}}}{S}\left(\frac{2}{2 + \psi}\right)^{1-\frac{1}{S}}$$

$$C_k = \frac{\gamma^{\frac{1}{S}}}{S} \left(\frac{2}{2+\psi} \right)^{-\frac{1}{S}}$$

$$M_1 = \frac{2}{S(2+\psi)}$$

$$M_k = \frac{1}{S}$$

$$n_1 = \frac{1}{S} \left(1 + \frac{2+\psi}{2}(S-1) \right) + \psi$$

$$n_k = \frac{1}{S} \left(\frac{2+\psi}{2} + S - 1 \right)$$

And equally-weighted welfare is

$$\mathcal{W}^{\text{one adjusts}} = \ln C_1 - n_1 + \ln \left(\frac{M_1}{P} \right) + (S-1) \left[\ln C_k - n_k + \ln \left(\frac{M_k}{P} \right) \right]$$

which can be showns is equal to

$$\mathcal{W}^{\text{one adjusts}} = 2 \left[\ln(\gamma) - S \ln(S) \right] - \left(\psi + \psi \frac{S-1}{S} + S \right) \tag{73}$$

Note that plugging in $\gamma = 1$ and $\psi = 0$ gives $\mathcal{W} = -2S \ln(S) - S$ which is steady state welfare.

All Sectors Adjust. Suppose now that all sectors adjust in such a way that the price level stays fixed. This means $P = P^* = 1$. Symmetry across sectors $k > 1$ implies we can treat these sectors as identical and consider the money supply M_k for each sector. In turn $M_1 = M^* - \frac{S-1}{S} M_k$.

The price level will be

$$P = 1 = S p_1^{\frac{1}{S}} \cdot p_k^{\frac{S-1}{S}}$$

from which we can derive the relationship between the prices of the sectors:

$$p_k = \left(S^S p_1 \right)^{\frac{1}{1-S}} = p_1 \left(S p_1 \right)^{-\frac{S}{S-1}}$$

We can then write consumption as

$$\begin{cases} C_1 = \gamma p_1 \\ C_k = p_1 \left(S p_1 \right)^{-\frac{S}{S-1}} \end{cases}$$

Total consumption then is

$$C = p_1 \left[\gamma + (S-1)(Sp_1)^{-\frac{S}{S-1}} \right]$$

This also equals PY and so sectoral demand is

$$y_1 = \frac{1}{S}\frac{PY}{p_1} = \frac{1}{S}\left[\gamma + (S-1)(Sp_1)^{-\frac{S}{S-1}} \right]$$

$$y_k = \frac{1}{S}\frac{PY}{p_k} = \frac{1}{S}\left[\gamma (Sp_1)^{\frac{S}{S-1}} + (S-1) \right]$$

This immediately lets us pin down labor demand into production $n_1 = \frac{1}{S}\frac{1}{\gamma}\left[\gamma + (S-1)(Sp_1)^{-\frac{S}{S-1}} \right]$ and $n_k = \frac{1}{S}\left[\gamma (Sp_1)^{\frac{S}{S-1}} + (S-1) \right]$. Because all sectors pay the menu cost, we have

$$N_1 = \frac{1}{S}\frac{1}{\gamma}\left[\gamma + (S-1)(Sp_1)^{-\frac{S}{S-1}} \right] + \psi$$

$$N_k = \frac{1}{S}\left[\gamma (Sp_1)^{\frac{S}{S-1}} + (S-1) \right] + \psi$$

Further note that $W_1 = p_1 \gamma$ and $W_k = p_k = p_1 (Sp_1)^{-\frac{S}{S-1}}$.

While we can solve for the relative price between sectors 1 and k, this is not necessary to compute welfare.

$$\mathcal{W}^{\text{all adjust}} = \ln(C_1) + (S-1)\ln(C_k) + \ln(M_1/P) + (S-1)\ln(M_k/P) - N_1 - (S-1)N_k$$

The first four terms boil down to

$$\ln(C_1) + (S-1)\ln(C_k) + \ln(M_1/P) + (S-1)\ln(M_k/P) = 2[\ln(C_1) + (S-1)\ln(C_k)]$$

plugging in the expressions for C_1 and C_k, we have

$$
\begin{aligned}
2[\ln(C_1) + (S-1)\ln(C_k)] &= 2\left[\ln(\gamma p_1) + (S-1)\ln\left(p_1(Sp_1)^{-\frac{S}{S-1}} \right) \right] \\
&= 2\left[\ln(\gamma) + \ln(p_1) + (S-1)\ln(p_1) - S\ln(S) - S\ln(p_1) \right] \\
&= 2\left[\ln(\gamma) - S\ln(S) \right]
\end{aligned}
$$

which is the same exact term deriving from the consumption and real money balances from the one-sector adjusting only. This result is expected since the two economies are

undistorted as relative prices have adjusted.

All we need to do is compare the labor disutility in the two economies. In the "all-adjust" economy, we have

$$
\begin{aligned}
N^{\text{all adjust}} &= N_1 + (S-1)N_k = \frac{1}{S} + \frac{S-1}{S\gamma}(Sp_1)^{-\frac{S}{S-1}} + \frac{(S-1)^2}{S} + \frac{S-1}{S}\gamma(Sp_1)^{\frac{S}{S-1}} + S\psi \\
&= S\psi + \frac{1+S^2-2S+1}{S} + \frac{S-1}{S\gamma}(Sp_1)^{-\frac{S}{S-1}} + \frac{S-1}{S}\gamma(Sp_1)^{\frac{S}{S-1}} \\
&= S\psi + (S-2) + \frac{2}{S} + \frac{S-1}{S}\underbrace{\left[\frac{1}{\gamma(Sp_1)^{\frac{S}{S-1}}} + \gamma(Sp_1)^{\frac{S}{S-1}}\right]}_{>2} \\
&> S\psi + (S-2) + \frac{2}{S} + 2\frac{S-1}{S} = S\psi + S
\end{aligned}
$$

while total labor in the "one-sector adjusts" economy is $N^{\text{one adjusts}} = \psi\left(\frac{2S-1}{S}\right) + S$ Therefore

$$
\begin{aligned}
\mathcal{W}^{\text{one adjusts}} - \mathcal{W}^{\text{all adjust}} &= -(N^{\text{one}} - N^{\text{all}}) = S\psi + S - \psi\left(\frac{2S-1}{S}\right) - S = \psi\frac{S^2-2S+1}{S} \\
&= \psi\frac{(S-1)^2}{S} > 0 \tag{74}
\end{aligned}
$$

Therefore, in the version of the model in which labor markets are segmented, we still have that the central bank should aim to have only sector 1 change its price in response to a productivity shock to sector 1.