Fair prices, sticky information, and the business cycle*

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Abstract

A fair price model in which firms are hesitant to raise their prices due to concerns about adverse consumer reactions is developed and integrated into the standard New Keynesian framework. In the model, monetary neutrality arise as a combination of a fairness constraint putting a limit on how high prices can be set over households’ projections of firms’ marginal cost, and households’ limited ability to accurately observe marginal cost. I show analytically that the model is consistent with a plethora of outcomes, ranging from complete monetary neutrality to generating substantial real effects. When plausible values are assigned to parameters and prices are strategic complements, business cycle dynamics closely resembles that in the sticky information model proposed by Mankiw and Reis (2002).

Keywords: Price Setting; Fairness Concerns; Sticky Information; Monetary Non-Neutrality

JEL codes: E31; E32

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1 Introduction

Traditional explanations to why prices are sticky, such as menu costs or information costs, remain the most popular frameworks for modeling price setting frictions. These models have the ability to generate business cycles of the same magnitude and persistence as found in data. Yet, when firms are asked about prices, the most common explanation to why prices are sticky is the fear of adverse customer reactions, while menu costs or information frictions are considered to be of the least importance (Apel et al., 2005, Amirault et al., 2006, Fabiani et al., 2007). Recognizing this discrepancy, Rotemberg (2005) proposes an alternative model where firms are hesitant to raise their prices because they fear adverse reactions if the price is considered to be unfair. Such a model is arguably more consistent with firm behavior at the micro level, but the question is whether it also has the potential to generate plausible dynamics at the macro level? In this paper, I attempt to answer this question by integrating a simple fair pricing model into the standard New Keynesian framework, and study its implications for business cycle dynamics with an eye towards evaluating its ability to generate monetary non-neutrality of plausible magnitude.

In the spirit of Rotemberg (2005), the model is based on two fundamental assumptions. First there is a fairness constraint saying that prices cannot be set too high over marginal cost without being considered unfair. This is consistent with the survey evidence in, e.g., Kahneman et al. (1986), who finds that customers generally only consider price raises that coincide with increases in cost to be fair, while price raises that are due to increases in demand are considered unfair.

Second, there is a constraint on household’s ability to accurately observe firms’ marginal costs. This assumption is implemented by assuming that information is sticky and households in a variant of the mechanism developed by Mankiw and Reis (2002)

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1. The predominantly used Calvo (1983) model is both consistent with a menu cost model where the menu cost randomly switches between being zero and being infinitely large, or an information friction model where the cost of acquiring information is extremely large (see Woodford, 2009).

only occasionally receive new information about firms’ marginal costs. This assumption is intuitively appealing, as it is unlikely that households know the marginal cost of stores that they patronize with certainty. While most consumers probably can make a rough estimate of the firm’s cost of a product they are about to purchase, it is unlikely that many can pinpoint is exactly.

The way that fair prices are modeled in this paper, however, differs from the approach taken in Rotemberg (2005) in several aspects. First, I do not explicitly derive the fairness norm from preferences, but postulate a norm that is reasonable based on evidence in survey studies; while less elaborate than the approach taken by Rotemberg, it is sufficient for the purpose of this paper. Second, I relax the assumption that consumers only evaluate the fairness of a firm’s price when the price changes. Surely, if a consumer observes that a firm’s cost have declined without a corresponding decrease in the price, he also realizes that the firm has increased its profit margin. Third, while Rotemberg assumes that households observe true marginal costs with measurement error, I instead, as mentioned above, assume that households occasionally receive up-to-date information about marginal costs, but no new information in-between such events. This allows me to compare aggregate dynamics in the fair price model with aggregate dynamics in the standard sticky information model proposed by Mankiw and Reis (2002, henceforth MR), where firms are assumed to be imperfectly informed about their own marginal cost, without having to account for differences in how information is received and processed.

In fair price the model, prices can not be set too high, as this would violate the fair pricing constraint. One might be tempted to conclude that this leads to asymmetric business cycles where expansions in nominal aggregate demand have real effects, but contractions are neutral because there is no constraint on how low prices can be set. But perhaps firms sometimes find it optimal to cut their prices less than the fall in marginal cost in order to increase their profit margins? I show that this conjecture is valid, and the model able to produce symmetric or nearly symmetric business cycles, for a wide range

3. In this paper, I will assume that not lowering the price when cost declines is considered as unfair as raising the price when cost has not risen. The survey evidence in Kahneman et al. (1986), however, indicate that the former is viewed as less unfair. Introducing such an asymmetry would be an interesting extension of the model for future work.
of parameter values. In fact, for a reasonable configuration of key parameters and given that prices are strategic complements, aggregate dynamics closely resembles that in the MR model.

This suggests that the aggregate dynamics generated by the MR model model can be reinterpreted as coming from households' rather than firms' limited information about firms' marginal cost. Thus, arguably, making the model immune to the criticism that firms generally regard them selves as being well-informed about the environment in which they operate. As pointed out by Rotemberg (2005), firms have huge incentives to acquire all relevant information, but it is more difficult to imagine that consumers are equally well-informed.

The remainder of this paper is organized as follows: In the section below, I describe the economic environment. Section 3 provides a closed form solution to the baseline model and in Section 4 I discuss the model’s ability to generate monetary non-neutrality. Section 5 presents the results from the numerical simulations. Section 6 considers an extension of the model where prices are strategic complements. Section 7 performs a sensitivity analysis. Section 8 concludes.

2 The economic environment

This section describes the behavior of households and firms in the economy.

2.1 Households

The economy is populated by a continuum of identical households on the unit interval. The representative household derives utility from the consumption of different goods, indexed by \( i \in (0, 1) \), according to the aggregator

\[
C_t = \left[ \int_{S_t} C_t(i)^{\frac{\epsilon - 1}{\epsilon}} \, di \right]^{\frac{\epsilon}{\epsilon - 1}},
\]

(1)

4. Rotemberg (2005) circumvents this problem by assuming that trend inflation is sufficiently high so that firms never find it optimal to cut their prices, but here I show that the model generates nearly symmetric business cycles even in an environment with zero trend-inflation.
where \( C_t(i) \) denotes the household’s consumption of good \( i \) and \( S_t \subseteq (0, 1) \) denotes the set of goods that the household actually consumes. The household’s utility is

\[
E_0 \sum_{t=0}^{\infty} \beta^t \{ \log C_t - N_t \},
\]

where \( \beta \in (0, 1) \) is the subjective discount factor and \( N_t \) is the number of working hours it supplies to the labor market.\(^5\) The household’s budget constraint is

\[
\int_0^1 C_t(i) P_t(i) \, di + Q_t B_t = B_{t-1} + W_t N_t + \Phi_t, \quad (3)
\]

where \( P_t(i) \) is the price of good \( i \), \( Q_t \) the price of a bond that pays off one tomorrow, \( B_t \) the household’s end of period bond holdings, \( W_t \) the nominal wage, and \( \Phi_t \) dividends from firm ownership.

The household’s problem is to maximize (2), subject to (1) and (3), and a fairness constraint saying that the household stops purchasing good \( i \) if the price exceeds the households’ notion of the fair price, \( P_t^F(i) \).\(^6\) This yields a demand function for good \( i \), given by

\[
C_t(i) = \begin{cases} 
(P_t(i))^{-\epsilon} C_t & \text{if } P_t(i) \leq P_t^F(i) \\
0 & \text{otherwise}
\end{cases}, \quad (4)
\]

where

\[
P_t = \left[ \int_{S_t} P_t(i)^{1-\epsilon} \, di \right]^{\frac{1}{1-\epsilon}} \quad (5)
\]

is the price level: The minimum cost for which the household can purchase one unit of the optimally composed consumption basket \( C_t \). Combining the first order conditions for consumption and bond holdings yields the consumption Euler equation

\[
Q_t = \beta E_t \left\{ \left( \frac{C_{t+1}}{C_t} \right)^{-1} \left( \frac{P_t}{P_{t+1}} \right) \right\}, \quad (6)
\]

\(^5\) This particular form of the utility function ensures that marginal cost is exogenous, which makes it possible to solve the model analytically. In section 6, I consider a model where marginal cost is endogenous, which allows for a more general utility specification.

\(^6\) See Section 2.3 below for a description on how the fair price is determined.
The first order condition for labor supply yields

\[ C_t = \frac{W_t}{P_t}. \] (7)

### 2.2 Firms

Good \( i \) is produced by a monopolist with technology

\[ Y_t(i) = N_t(i)e^{-z_t(i)}, \] (8)

where \( Y_t(i) \) is output, \( N_t(i) \) the input of labor in production, and \( z_t(i) \) is an idiosyncratic component of production which evolves according to the AR(1) process

\[ z_t(i) = \rho z_{t-1}(i) + \epsilon_t(i), \] (9)

where \( \epsilon_t \) is drawn from a \( N(0, \sigma^2) \) distribution. Imposing goods market clearing, \( Y_t(i) = C_t(i) \), the firm’s time \( t \) problem is to maximize its profit

\[ \left[ P_t(i) - W_t e^{z_t(i)} \right] \left( \frac{P_t(i)}{P_t} \right)^{-\epsilon} C_t, \] (10)

subject to the fairness constraint \( P_t(i) \leq P_t^F(i) \).

I assume that the firm never finds it optimal to stop producing. In a strict interpretation, this requires that the fair price exceeds marginal cost at all times. It is however easy to imagine that also stock-outs can cause adverse customer reactions, and that firms therefore are willing to incur temporary losses to avoid “badwill” and potentially negative effects on long term profits. In addition, there may be fixed costs associated with starting up and closing down production.\(^7\)

\(^7\) In Appendix D, I solve a version of the model where firms instead stop producing when the fair price is lower than marginal cost. As it turns out, this alternative assumption has negligible effects on aggregate dynamics.
The firm’s optimal price must satisfy the condition

\[ P_t(i) = \min \left\{ P^D_t(i), P^F_t(i) \right\}, \quad (11) \]

where \( P^D_t(i) = M^D MC_t(i) \) is the firm’s desired price, in which \( M^D = \varepsilon / (\varepsilon - 1) \) is the desired markup and \( MC_t(i) = Wte^{zi(i)} \) the firm’s nominal marginal cost. The firm will set the desired price if that price is below the fair price; otherwise it will set the fair price.

### 2.3 The fair price

I assume that households allow firms to set their prices as a fixed markup over marginal costs. But households are imperfectly informed about firms’ marginal costs. In particular, in any given period, households receive new information about a firm’s marginal cost with probability \((1 - \theta)\). Using this up-to-date information, households update their projections about current and future marginal costs and revise their plans for the evolution of the fair price.\(^8\) With probability \(\theta\), new information does not arrive and households do not revise their plans.

Under these assumptions, the fair price at firm \(i\) when households last received new information about marginal cost \(k\) periods ago is given by

\[ P^F_t(i) = M^F E_{t-k} MC_t(i), \quad (12) \]

where \( M^F \) will be referred to as the fair markup. In general, there is no reason to expect the fair markup to equal the desired markup. Admittedly simple, this specification captures the spirit of the findings in Kahneman et al. (1986): Firms are allowed to protect them selves from losses relative to some reference level, even if that entails raising the price and making their consumers worse off.

\(^8\) For simplicity, I assume that all households have the same information about marginal cost at a particular firm. Moreover, firms are assumed to know the fair price with certainty.
2.4 Aggregate demand

The monetary authority is assumed to conduct monetary policy so that nominal aggregate demand, $S_t = C_t P_t$, evolves according to the process

$$\log S_t = \log S_{t-1} + \eta_t,$$  \hspace{1cm} (13)

where $\eta_t$ is drawn from a $N \left(0, \sigma^2_\eta\right)$ distribution.\(^9\)

3 The baseline model

Given the assumptions about log utility in consumption and linear disutility of labor, marginal cost is exogenous, and the model can be solved analytically. From (7) and the definition of $S_t$, it follows that the nominal wage in the economy is given by

$$W_t = C_t P_t = S_t.$$ \hspace{1cm} (14)

A firm’s marginal cost is then given by

$$MC_t (i) = W_t e^{z_t(i)} = S_t e^{z_t(i)}$$ \hspace{1cm} (15)

and evolves exogenously. Consider a firm where the fair price is based on $k$ period old information. The log optimal price of the firm is given by

$$\log P_{t|t-k} (i) = \min \left\{ \log M^D + \log S_t + z_t(i), \log M^F + \log E_{t-k} S_t + \log E_{t-k} e^{z_t(i)} \right\}.$$ \hspace{1cm} (16)

This can, imposing the approximate log-linear relations $\log E_{t-k} S_t = E_{t-k} \log S_t$ and $\log E_{t-k} e^{z_t(i)} = E_{t-k} \log e^{z_t(i)}$, and using (13), be rewritten as

$$\log P_{t|t-k} (i) = \min \left\{ \log M^D + \log S_t + z_t(i), \log M^F + \log S_{t-k} + \rho^k z_{t-k} (i) \right\}.$$ \hspace{1cm} (17)

9. For brevity, I will typically omit “nominal” and simply refer to $S_t$ as aggregate demand.
Alternatively, this can be expressed as

\[
\log P_{t|t-k} (i) = \begin{cases} 
\log \mathcal{M}^D + \log S_t + z_t (i) & \text{if } z_t (i) < \bar{z}_{t|t-k} (i) \\
\log \mathcal{M}^F + \log S_{t-k} + \rho^k z_{t-k} (i) & \text{otherwise}
\end{cases},
\]  

(18)

where

\[
\bar{z}_{t|t-k} (i) = -M_{\text{gap}} - (\log S_t - \log S_{t-k}) + \rho^k z_{t-k} (i)
\]

(19)
denotes the value of the \( z_t (i) \) that makes the firm indifferent between setting the desired price and the fair price, in which \( M_{\text{gap}} \equiv \log \mathcal{M}^D - \log \mathcal{M}^F \) denotes the markup gap (the log difference between the desired markup and the fair markup). In other words, if \( z_t (i) < \bar{z}_{t|t-k} (i) \) the firm will be price unconstrained and set the desired price, while it will be price constrained and set the fair price otherwise.

It is convenient to define a new variable \( x_{t|t-k} (i) \equiv z_t (i) - \bar{z}_{t|t-k} (i) \). In this formulation, a firm will set the desired price if \( x_{t|t-k} (i) < 0 \) and the fair price otherwise. In Appendix A, I show that the time \( t \) distribution of this variable across firms is \( N (-\mu_{t,k}, \sigma_{x,k}^2) \), where

\[
\mu_{t,k} = -M_{\text{gap}} - (\log S_t - \log S_{t-k}),
\]

(20)

\[
\sigma_{x,k}^2 = \frac{(1 - \rho^2 k)}{(1 - \rho^2)} \sigma_x^2.
\]

(21)

It follows that a proportion \( F (\mu_{t,k}/\sigma_{x,k}) \) of the firms with a fair price based on \( k \) period old information will set the desired price, and a proportion \( 1 - F (\mu_{t,k}/\sigma_{x,k}) \) will set the fair price.\(^{10}\) Hence, the average log price of those firms is given by

\[
\log \bar{P}_{t|t-k} = F (\mu_{t,k}/\sigma_{x,k}) \left[ \log \mathcal{M}^D + \log S_t + \phi (\mu_{t,k}/\sigma_{x,k}) \right] \\
+ \left[ 1 - F (\mu_{t,k}/\sigma_{x,k}) \right] \left[ \log \mathcal{M}^F + \log S_{t-k} \right],
\]

(22)

\(^{10}\) \( F (\cdot) \) denotes the cdf of the standard normal function, and where it is understood that if \( \sigma_{x,k} = 0 \), \( F (\mu_{t,k}/\sigma_{x,k}) = 0 \) if \( \mu_{t,k} < 0 \) and \( F (\mu_{t,k}/\sigma_{x,k}) = 1 \) if \( \mu_{t,k} > 0 \).
where
\[ \phi \left( \mu_{t,k} / \sigma_{x,k} \right) \equiv E_i \left\{ z(i) \mid x_{t|t-k} (i) < 0 \right\} = -\sigma_{x,k} \frac{f \left( \mu_{t,k} / \sigma_{x,k} \right)}{F(\mu_{t,k} / \sigma_{x,k})} \leq 0, \]  
(23)

using the notation \( E_i \left\{ z(i) \mid x_{t|t-k} (i) < 0 \right\} \) for the conditional mean of \( z_t(i) \) across those firms who set the desired price.\(^{11}\)

Using a log-linear approximation to (5), the log price level can be written as
\[ \log P_t = (1 - \theta) \sum_{k=0}^{\infty} \theta^k \log \tilde{P}_{t|t-k}, \]
(24)

which can be decomposed as
\[ \log P_t = \log P^F_t + \varphi_t, \]
(25)

where
\[ \log P^F_t = (1 - \theta) \sum_{k=0}^{\infty} \theta^k \left[ \log M^F + \log S_{t-k} \right] \]
(26)

is the hypothetical log price level should all firms set the fair price, and
\[ \varphi_t = (1 - \theta) \sum_{k=0}^{\infty} \theta^k F \left( \mu_{t,k} / \sigma_{x,k} \right) \left[ -\mu_{t,k} + \phi \left( \mu_{t,k} / \sigma_{x,k} \right) \right] \leq 0 \]
(27)

is a “correction term” measuring the negative effect on the log price level exerted by those firms that undercut the fair price and set the desired price instead.\(^{12}\)

4 Model properties

In this section, I discuss the fair price model’s ability to generate monetary non-neutrality and how it relates to the MR model. The crucial difference between the two models is that in the fair price model, firms are sometimes able to adjust to a change in aggregate demand, even though their fair prices are based on outdated information, by undercutting the fair price and setting the desired price. In the MR model, on the other hand, firms

\(^{11}\) See Appendix B for a derivation of equation (23).
\(^{12}\) That this term is non-positive follows directly from (B.4) in Appendix B.
that base their decisions on outdated information are never able to adjust to a change in aggregate demand.

As the proportion of firms setting the desired price goes to zero at all times, the fair price model converges to the MR model. In this case, the correction term goes to zero and the evolution of the price level is the same in both models. They therefore also generate the same degree of monetary non-neutrality. A simple measure of the degree of monetary non-neutrality is the cumulative impulse response (CIR) of output, which I define as $\text{sgn}(\eta) \sum_{j=0}^{\infty} \left( \log C_{t+j} - \log \bar{C} \right)$, where $\eta$ is the size of a one-time shock to log aggregate demand and $\bar{C}$ denotes the steady state level of output. It is straightforward to show that in this case, the CIR is given by $\text{sgn}(\eta) \left( \frac{\theta}{1 - \theta} \eta \right)$, regardless the direction of the shock. For a shock of given size, the degree of monetary non-neutrality depends only on $\theta$, the parameter governing the frequency of information update. The less frequent information is updated, the larger the degree of monetary non-neutrality.

At the other extreme, when the proportion of firms setting the desired price goes to one at all times, the fair price model converges to the frictionless equilibrium. The evolution of the price level is the same as when $\theta$ is set to zero. The CIR is zero and changes in aggregate demand have no effects on real output. But in the more general case, when the proportion of firms that set the desired price is less than one but greater than zero, the model still generates monetary non-neutrality, but of smaller magnitude than in the MR model. Some of the firms whose fair price is based on outdated information are able to adjust to a change in aggregate demand, while others are not, increasing the flexibility of the price level, but not to such an extent that nominal shocks are neutral.

Thus, in contrast to the Calvo or MR model, monetary non-neutrality is not hardwired into the fair price model. Instead, it is consistent with a spectrum of different outcomes, ranging from complete monetary neutrality to the economy being observationally equivalent to the MR model. Which outcome we observe crucially depends on the size

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13. This corresponds to the case when $F(\mu_{t,k}/\sigma_{x,k}) \to 0$ for all $k \geq 0$ at all times.
14. The markup may be different, but this only has an average effect on the price level and does not affect the response to shocks.
15. The steady state is defined as the state the economy converges to in the absence of aggregate shocks.
16. This corresponds to the case when $F(\mu_{t,k}/\sigma_{x,k}) \to 1$ for all $k \geq 0$ at all times.
of the markup gap relative the volatility of marginal cost. To see this, note that for a price constrained firm, $M^{gap}$ is the most log marginal cost can fall below projected log marginal cost without the firm becoming price unconstrained. Therefore, if the markup gap is sufficiently positive relative to the volatility of marginal cost, so that no firm ever prefers to set the desired price, aggregate dynamics is the same as in the MR model. For a price unconstrained firm, on the other hand, $-M^{gap}$ is the most log marginal cost can rise above projected log marginal cost without the firm becoming price constrained. Therefore, if $M^{gap}$ is sufficiently negative relative to the volatility of marginal cost, so that all firms set the desired price at all times, the frictionless equilibrium is replicated and there is monetary neutrality. But if the relation between $M^{gap}$ and the volatility of marginal cost instead is such that firms sometimes set the fair price and sometimes the desired price, real output is affected by nominal shocks, but the degree of monetary neutrality is smaller than in the MR model.

The above reasoning also explains why the model can generate real effects to contractions in aggregate demand, despite there being no formal constraint on how low prices can be set. Firms that are price constrained prefer to increase their markups rather than lower their prices when marginal cost falls. Thus, given that at least some firms are price constrained when aggregate demand contracts, this also leads to a contraction in real output. Similarly but conversely, if all firms are price unconstrained when aggregate demand expands, the model sometimes fails to produce real effects, despite the fact that there is a constraint on how high prices can be set; if the expansion in aggregate demand is not too large (so that some firms become price constrained), all firms can immediately adjust to the aggregate shock without violating the fair price constraint. Thus, it is far from certain that the model produces so vastly asymmetric business cycles as one might be compelled to believe based on the fact that there is only a constraint on how high prices can be set.

17. Suppose for instance that a firm’s fair markup is 15% and the desired markup is 25%. For a firm that is price constrained, its marginal cost can at most fall (approximately) 10% below projected marginal cost without the firm becoming price unconstrained.
Table 1: Baseline calibration.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta$</td>
<td>0.75</td>
<td>Sticky information parameter</td>
</tr>
<tr>
<td>$M^D$</td>
<td>1.67</td>
<td>The desired markup</td>
</tr>
<tr>
<td>$M^F$</td>
<td>1.37</td>
<td>The fair markup</td>
</tr>
<tr>
<td>$\sigma_\eta$</td>
<td>0.01</td>
<td>Standard deviation of growth rate of nominal aggregate demand</td>
</tr>
<tr>
<td>$\sigma_\epsilon$</td>
<td>0.21</td>
<td>Standard deviation of the idiosyncratic shock</td>
</tr>
<tr>
<td>$\rho$</td>
<td>0.75</td>
<td>Serial correlation of the cost shock</td>
</tr>
</tbody>
</table>

Note: The table shows the baseline calibration used in the numerical simulations.

5 Simulations

As shown in the section above, business cycle dynamics in the fair price model crucially depends on the value of the model’s parameters. In this section, I calibrate the model to investigate its ability to generate monetary non-neutrality when plausible values are assigned to parameters.

The model is calibrated to a quarterly periodicity. Following Mankiw and Reis (2002), $\theta$ is set to 0.75, implying that households update their projections about marginal cost with new information for 25% of the firms every quarter. Based on the standard deviation of nominal GDP growth in the U.S. between 1960 and 2012, $\sigma_\eta$ is set to 0.01. The desired gross markup, $M^D = \varepsilon / (\varepsilon - 1)$, is calibrated to get an elasticity of substitution, $\varepsilon$, of 2.5, which is consistent with the evidence in Broda and Weinstein (2006). The autoregressive coefficient of the cost shock, $\rho$, is set to 0.75. Finally, the values of $\sigma_\epsilon$ and $M^F$ are calibrated to match an average absolute size of price changes of 10% and an average markup in the economy of 33%.\footnote{The distribution of prices changes was obtained by simulating the model for 100000 periods.} The average absolute size of price changes is roughly consistent with the findings in Klenow and Kryvtsov (2008), and the average markup with the estimates in Nevo (2001). This calibration implies that the steady state proportion of firms setting the fair price is 82.7%.

Figure 1 shows impulse responses of output, inflation, and the proportion of firms setting the desired price to both a one standard deviation increase and a one standard

18. The distribution of prices changes was obtained by simulating the model for 100000 periods.
Figure 1: Impulse responses of output, inflation, and the proportion of firms setting the fair price to a one standard deviation increase and to a one standard deviation decrease in nominal aggregate demand.

deviation decrease in nominal aggregate demand.\textsuperscript{19} The solid lines are the responses in the fair price model, and the dashed lines the responses in the MR model. The expansion in aggregate demand leads to a persistent increase in output and inflation in both models (and vice versa for the contraction in demand). The output response is weaker in the fair price model, the CIR being only about 75% of that in the MR model. Due to the increased flexibility of the price level in the fair price model, brought about by the firms that adjust to the aggregate shock by setting the desired price, there is a larger initial reaction of the price level, and a smaller degree of monetary non-neutrality.

Note that in the fair price model, the markup gap is apparently sufficiently large relative to the fluctuations in marginal cost to generate nearly symmetric business cycles. The CIR for the expansion in aggregate demand is only 1.4% larger than the CIR for the

\textsuperscript{19} Note that calculating the price level involves calculating an infinite number of lags of nominal aggregate demand. In the numerical simulations, I therefore replace (24) with

\[ \log P_t = (1 - \theta) \sum_{k=0}^{N} \theta^k \log \tilde{P}_{t|t-k}. \]  

For the experiments conducted here, I have used $N = 80$. Increasing $N$ has extremely small effects on the results.

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contraction: When aggregate demand contracts, most firms find it optimal to increase their markups rather than lower their prices.

6 A model with endogenous marginal cost

The baseline version of the fair price model considered above generates substantially less monetary non-neutrality than the MR model. But in the baseline model, marginal cost is exogenous, varying one-for-one with aggregate demand. While this makes it possible to solve the model analytically, the model is too simplistic to be realistic.

In this section, I instead consider a specification where marginal cost is endogenous and a change in aggregate demand only has a limited effect on marginal cost. In particular, marginal cost is assumed to be given by

\[ MC_t(i) = S_t^{1-\Psi} P_t^\Psi e^{z_t(i)}, \]  

(29)

where \( \Psi \in [0, 1) \).\(^{20}\) In this specification, the average log price of the firms with a fair price based on \( k \) period old information is given by

\[
\log \bar{P}_{t|t-k} = F(\mu_{t,k}/\sigma_{x,k}) \left[ \log M^D + (1 - \Psi) \log S_t + \Psi \log P_t + \phi(\mu_{t,k}/\sigma_{x,k}) \right] \\
+ (1 - F(\mu_{t,k}/\sigma_{x,k})) \left[ \log M^F + (1 - \Psi) \log S_{t-k} + \Psi E_{t-k} \log P_t \right],
\]

(30)

where

\[
\mu_{t,k} = -M^pp - (1 - \Psi) (\log S_t - \log S_{t-k}) - \Psi (\log P_t - E_{t-k} \log P_t),
\]

(31)

and \( \sigma_{x,k}^2 \) as before by (21). This model cannot easily be solved due to the presence of lagged expectations on the right hand sides of (30) and (31). Instead, I simulate impulse responses using numerical methods.\(^{21}\)

In the simulations, I will set \( \Psi = 0.95 \), which has been found to generate output

\(^{20}\) This specification could be due to, e.g., intermediate inputs; see Nakamura and Steinsson (2010).\(^{21}\) See Appendix C for details.
responses with similar persistence as in empirical studies. The remaining parameters are kept at the same values as before. As is evident from Figure 2, endogenous marginal cost increases the intensity and persistence of the output response in both models. The reason is that in this specification, prices are strategic complements and the bulk of the variation in marginal cost is due to changes in the price level. In the baseline model, firms that have not yet adjusted their prices to the aggregate shock have no effect on the prices set by the other firms in the economy. But when prices are strategic complements, the mitigating effect the non-adjusters exert on the price level also mutes the price response of the other firms in the economy. This slows down the adjustment of the price level and generates larger real effects in both model. But the effect is relatively stronger in the fair price model, where a larger proportion of the firms have the ability to adjust when the aggregate shock hits, the CIR now being 90% of that in the MR model.

22. See, e.g., the discussion in Woodford (2003, chap. 3).
23. Since only an impulse response is simulated, I am unable to check if this calibration still yields an average absolute size of price changes consistent with data. Importantly, however, the specification in (29) does not mute the price response to idiosynchatic shocks, which accounts for the bulk of price movements in the baseline model.
24. See the discussion in, e.g., Haltiwaner and Waldman (1989) and Fehr and Tyran (2008).
Table 2: Sensitivity analysis.

<table>
<thead>
<tr>
<th>Changed parameter</th>
<th>$\theta$</th>
<th>$\sigma_s$</th>
<th>$M_D$</th>
<th>$\sigma_\epsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>New value</td>
<td>0.80</td>
<td>0.03</td>
<td>1.5</td>
<td>0.31</td>
</tr>
<tr>
<td>Fair prices (+)</td>
<td>+30.4%</td>
<td>+200.7%</td>
<td>-6.5%</td>
<td>-3.8%</td>
</tr>
<tr>
<td>Fair prices (-)</td>
<td>+30.2%</td>
<td>+199.3%</td>
<td>-6.8%</td>
<td>-3.7%</td>
</tr>
<tr>
<td>MR</td>
<td>+30.5%</td>
<td>+200%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Note: The table shows the percentage change in the CIR when one parameter is varied, while the others are kept at their baseline values. (+) indicates that the shock was positive; (−) that the shock was negative.

7 Sensitivity analysis

The extension of the baseline model with endogenous marginal cost generates business cycles of similar magnitude and persistence as in the MR model. In this section, I perform a sensitivity analysis where the percentage change in the CIR is calculated when the value of selected model parameters are changed from the baseline calibration.

The first experiment is to increase the value of $\theta$ so that the average interval between information updates increases from four to five quarters. This leads to an increase in the CIR by approximately 30% in both the fair price model (regardless the direction of the shock) and the MR model. Tripling the standard deviation of the aggregate shock, also triples the CIR in both models. The shock is still sufficiently small to generate essentially symmetric effects to expansions and contractions in aggregate demand in the fair price model.25

The CIR in the MR model is independent of both $M_D$ and $\sigma_\epsilon$. Decreasing the markup only has an average effect on the price level, but does not affect the response to shocks. Increasing the volatility of marginal cost increases the dispersion of prices, but this effect cancels out in the price level, and does not affect the response to shocks.

In the fair price model, on the other hand, a decrease in the desired markup leads to a decrease in the markup gap $M^{\text{gap}}$, while an increase in $\sigma_\epsilon$ leads to an increase the volatility of marginal cost relative to projected marginal cost. Both changes work to increase the incidence at which firms desired prices falls below their fair prices (cf. the discussion in

25. In order to get a CIR that is more than 5% larger for an expansion than for a contraction in aggregate demand, the size of the shock needs to be more than 17 times larger than in the baseline calibration.
increasing the flexibility of the price level and reducing the degree of monetary non-neutrality.

The decrease in $M^D$ to 1.5—corresponding to an increase in $\eta$ to 3 and a fall in the average markup from 33% to 30%—leads to a decrease in the CIR by 6.5% (6.8% for a contraction in demand). The 50% increase in the standard deviation of marginal cost leads to a fall in the average markup to 29% and a decrease in the CIR by 3.8% (3.7%). The fair price model thus suggests that the degree of monetary non-neutrality is positively related to the degree of market power (as measured by the average markup) and negatively related to the volatility of marginal cost.\textsuperscript{26}

8 Conclusions

Survey evidence indicate that the most important reason for why prices are sticky is firms’ fear of antagonizing its customers. Motivated by this fact, a model where fairness concerns puts a limit on how high prices can be set is developed. Combined with poorly informed households, the model has the potential to create sizable monetary non-neutrality.

It is shown that for a reasonable calibration and when prices are strategic complements, aggregate dynamics in the model closely resembles that in the MR model. Despite the fact that there only is a constraint on how high prices can be set, business cycles are almost symmetric. This is a result of that in order to match the size of the average markup found in data, the model must be calibrated so that most firms are price constrained in steady state. Most of the time, firms therefore prefer to increase their profit margins rather than lower their prices when aggregate demand falls.

A shortcoming that the model shares with most models where nominal rigidities are due to information frictions is that unless one imposes very specific assumptions about the evolution of marginal cost, so that future marginal cost always is expected to remain constant, prices will change all the time. This is inconsistent with empirical evidence,\textsuperscript{26} It is, however, important to emphasize that the relation between the degree of monetary non-neutrality and the economy’s average markup does not necessarily hold if the fair markup also is changed. If $M^F$ is reduced along with $M^D$, so that the $M^{gap}$ is unchanged, the CIR is also unchanged, but the economy’s average markup drops to 20%.
which suggests that prices on average remain constant for several quarters. But here it assumed that households know the true data generating process of marginal cost. In reality, this is quite unlikely. It may very well be that, in practice, the best projection, given available information, is for marginal cost not to change. This could give rise to an interesting pattern of price adjustment where firms most of the time set the fair price, which only changes occasionally, but also hold frequent “sales” when they undercut the fair price and set the desired price.
References


Appendix A

Using (19), \( x_{t|t-k} (i) \) can be written as

\[
  x_{t|t-k} (i) = z_t (i) - \mu_{t,k} - \rho^k z_{t-k} (i),
\]

where \( \mu_{t,k} \) is given by (20). Iterating backward on (9), yields

\[
  z_t (i) = \rho^k z_{t-k} (i) + \sum_{j=0}^{k-1} \rho^j \epsilon_{t-j} (i),
\]

and (A.1) can be written as

\[
  x_{t|t-k} (i) = -\mu_{t,k} + \sum_{j=0}^{k-1} \rho^j \epsilon_{t-j} (i).
\]

Since \( \rho^j \epsilon_{t-j} (i) \) is \( N(0, \rho^{2j} \sigma^2) \), it follows that \( x_{t|t-k} (i) \) is \( N(-\mu_{t,k}, \sigma^2_{x,k}) \), where

\[
  \sigma^2_{x,k} = \sum_{j=0}^{k-1} \rho^{2j} \sigma^2 = \frac{(1 - \rho^{2k})}{(1 - \rho^2)} \sigma^2.
\]

Appendix B

Using (A.1), the conditional expectation \( E_i \{ z_t (i) \mid x_{t|t-k} (i) < 0 \} \) can be written as

\[
  \begin{align*}
  E_i \{ x_{t|t-k} (i) + \mu_{t,k} + \rho^k z_{t-k} (i) \mid x_{t|t-k} (i) < 0 \} \\
  = E_i \{ x_{t|t-k} (i) \mid x_{t|t-k} (i) < 0 \} + E_i \{ \mu_{t,k} \mid x_{t|t-k} (i) < 0 \} + E_i \{ \rho^k z_{t-k} (i) \mid x_{t|t-k} (i) < 0 \} \\
  = E_i \{ x_{t|t-k} (i) \mid x_{t|t-k} (i) < 0 \} + \mu_{t,k} \\
  = -\mu_{t,k} - \sigma_{x,k} \frac{f (\mu_{t,k}/\sigma_{x,k})}{F (\mu_{t,k}/\sigma_{x,k})} + \mu_{t,k} \\
  = -\sigma_{x,k} \frac{f (\mu_{t,k}/\sigma_{x,k})}{F (\mu_{t,k}/\sigma_{x,k})}, \quad (B.1)
  \end{align*}
\]
where the third line follows from that the fact since $\mu_{t,k}$ is constant across $i$, and $\rho^k z_{t-k} (i)$ and $x_{t|t-k} (i)$ are independent, it must be that

$$E_i \left\{ \mu_{t,k} (i) | x_{t|t-k} (i) < 0 \right\} = \mu_{t,k}, \quad (B.2)$$

$$E_i \left\{ \rho^k z_{t-k} (i) | x_{t|t-k} (i) < 0 \right\} = E_i \left\{ \rho^k z_{t-k} (i) \right\} = 0, \quad (B.3)$$

and the fourth line from the property of the truncated normal distribution that

$$E_i \left\{ x_{t|t-k} (i) | x_{t|t-k} (i) < 0 \right\} = -\mu_{t,k} - \sigma_{x,k} \frac{f(\mu_{t,k}/\sigma_{x,k})}{F(\mu_{t,k}/\sigma_{x,k})} = -\mu_{t,k} + \phi(\mu_{t,k}/\sigma_{x,k}) \leq 0. \quad (B.4)$$

### Appendix C

Assume that the economy initially is in steady state, where log nominal aggregate demand is zero, and that a one-time shock to log aggregate demand shock of size $\eta$ occurs in period $t$. Under these assumptions, we have that

$$\log S_{t+j-k} = \begin{cases} \eta & \text{if } k \leq j \\ 0 & \text{otherwise} \end{cases}, \quad (C.1)$$

and

$$E_{t+j-k} \log P_{t+j} = \begin{cases} \log P_{t+j} & \text{if } k \leq j \\ \log \bar{P} & \text{otherwise} \end{cases}. \quad (C.2)$$
where $\bar{P}$ denotes the preshock price level. Using (30), (C.1), and (C.2) in (24), the log price level in period $t + j$ can be written as

$$
\log P_{t+j} = (1 - \theta) \sum_{k=0}^{j} \theta^k \left\{ [F (-\mathcal{M}^{gap}/\sigma_{x,k})] \left[ \log \mathcal{M}^D + (1 - \Psi) \eta + \Psi \log P_{t+j} + \phi (-\mathcal{M}^{gap}/\sigma_{x,k}) \right] \\
+ [1 - F (-\mathcal{M}^{gap}/\sigma_{x,k})] \left[ \log \mathcal{M}^F + (1 - \Psi) \eta + \Psi \log P_{t+j} \right] \right\} \\
+ (1 - \theta) \sum_{k=j+1}^{\infty} \theta^k \left\{ [F \left( (\mathcal{M}^{gap} - (1 - \Psi) \eta - \Psi \log P_{t+j} - \log \bar{P}) \right) \sigma_{x,k}] \right\} \\
\times \left[ \log \mathcal{M}^D + (1 - \Psi) \eta + \Psi \log P_{t+j} + \phi \left( (\mathcal{M}^{gap} - (1 - \Psi) \eta - \Psi \log P_{t+j} - \log \bar{P}) \sigma_{x,k} \right) \right] \\
+ [1 - F \left( (\mathcal{M}^{gap} - (1 - \Psi) \eta - \Psi \log P_{t+j} - \log \bar{P}) \sigma_{x,k} \right)] \\
\times \left[ \log \mathcal{M}^F + \Psi \log \bar{P} \right] \right\}.
$$

(C.3)

It is straightforward to solve the above equation for $\log P_{t+j}$ using numerical methods.

**Appendix D**

In this Appendix, I solve the baseline model under the alternative assumption that firms stop producing when the fair price is lower than marginal cost. For a firm whose fair price is based on $k$ period old information, it becomes optimal to stop producing when

$$
\log \mathcal{M}^F + \log S_{t-k} + \rho^k z_{t-k} (i) < \log S_t + z (i) .
$$

(D.1)

Let $\tilde{z}_{t,t-k} (i)$ denote the value of $z (i)$ for which the firm breaks even. It follows that

$$
\log \mathcal{M}^F + \log S_{t-k} + \rho^k z_{t-k} (i) = \log S_t + \tilde{z}_{t,t-k} (i) .
$$

(D.2)

Solving the above equation for $\tilde{z}_{t,t-k} (i)$, yields

$$
\tilde{z}_{t,t-k} (i) = \log \mathcal{M}^F - (\log S_t - \log S_{t-k}) + \rho^k z_{t-k} (i) ,
$$

(D.3)
which using (19) can be written as

\[ \tilde{z}_{t|t-k} (i) = \tilde{z}_{t|t-k} (i) + \log \mathcal{M}^D. \]  
\( \text{(D.4)} \)

We can then write the log optimal price of the firm as

\[ \log P_{t|t-k} (i) = \begin{cases} \log \mathcal{M}^D + \log S_t + z_t (i) & \text{if } z_t (i) < \tilde{z}_{t|t-k} (i) \\ \log \mathcal{M}^F + \log S_{t-k} + \rho^k z_{t-k} (i) & \text{if } \tilde{z}_{t|t-k} (i) \leq z_t (i) \leq \tilde{z}_{t|t-k} (i) + \log \mathcal{M}^D \end{cases}. \]  
\( \text{(D.5)} \)

Again defining \( x_{t|t-k} (i) \equiv z_t (i) - \tilde{z}_{t|t-k} (i) \), this can alternatively be expressed as

\[ \log P_{t|t-k} (i) = \begin{cases} \log \mathcal{M}^D + \log S_t + z_t (i) & \text{if } x_{t|t-k} (i) < 0 \\ \log \mathcal{M}^F + \log S_{t-k} + \rho^k z_{t-k} (i) & \text{if } 0 \leq x_{t|t-k} (i) \leq \log \mathcal{M}^D \end{cases}. \]  
\( \text{(D.6)} \)

If \( x_{t|t-k} (i) > \log \mathcal{M}^D \), the firm stops producing. The proportion of firms producing, of those with a fair price based on \( k \) period old information, is thus

\[ F \left( \log \mathcal{M}^D + \mu_{t,k} \right) / \sigma_{x,k} \}, \]  
and the log average price of those firms given by

\[ \log \bar{P}_{t|t-k} = \frac{F (\mu_{t,k} / \sigma_{x,k})}{F \left( \log \mathcal{M}^D + \mu_{t,k} \right) / \sigma_{x,k} } \left[ \log \mathcal{M}^D + \log S_t + \phi \left( \mu_{t,k} / \sigma_{x,k} \right) \right] + \frac{F \left( \log \mathcal{M}^D + \mu_{t,k} \right) / \sigma_{x,k} }{F \left( \log \mathcal{M}^D + \mu_{t,k} \right) / \sigma_{x,k} } \left[ \log \mathcal{M}^F + \log S_{t-k} \right]. \]  
\( \text{(D.7)} \)

The price level can again be composed as

\[ \log P_t = \log P_t^F + \varphi_t, \]  
\( \text{(D.8)} \)

where \( P_t^F \), given that at least some firms produce, still is given by (26), but the correction term modifies to

\[ \varphi_t = (1 - \theta) \sum_{k=0}^{\infty} \theta^k \frac{F (\mu_{t,k} / \sigma_{x,k})}{F \left( \log \mathcal{M}^D + \mu_{t,k} \right) / \sigma_{x,k} } \left[ -\mu_{t,k} + \phi \left( \mu_{t,k} / \sigma_{x,k} \right) \right] \leq 0. \]  
\( \text{(D.9)} \)
Using the same calibration as in the main text, 90.8% of the firms produce in the steady state, and 80.1% of those firms set the fair price. Figure 3 shows impulse responses of output, inflation and the proportion of firms setting the fair price (of those that produce) to a one standard deviation shock to nominal aggregate demand. The solid lines are the responses in the baseline model, and the dashed lines the responses under the alternative assumption that firms stop producing when the fair price is lower than marginal cost. As is evident from the figure, assuming that firms sometimes stop producing has negligible effects on aggregate dynamics.

It is straightforward to also modify the model with endogenous marginal cost so that firms stop producing when the fair price is lower than marginal cost. In this model too, aggregate dynamics is only negligibly affected.