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STICKY PRICES AND THE NOMINAL EFFECTS OF REAL SHOCKS

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Sticky Prices and the Nominal Effects of Real Shocks

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Abstract

Ball and Mankiw (1995) have proposed a novel theory of short-run inflation driven by relative price shocks and nominal rigidities. If firms only adjust prices in response to large shocks, the general price level increases when the distribution of idiosyncratic price shocks is skewed to the right. This type of skewness is interpreted as a negative aggregate supply shock. In Ball and Mankiw's model the inflationary effects of supply shocks are relatively small. This paper extends the Ball and Mankiw model by introducing interaction among price-setters. This implies firms take expected inflation into account when setting prices. In a rational expectations equilibrium the rate of inflation turns out to be substantially higher when individual prices respond to expected inflation. This result brings the Ball and Mankiw model's key quantitative predictions in line with the stylized facts on inflation and enhances its usefulness as an explanation of inflation variability.

Keywords: Supply shocks, inflation, menu costs.

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1 Introduction

The general consensus among macroeconomists is that inflation is predominantly a monetary phenomenon in the long run: shocks to real variables are taken to have little or no long-run effect on inflation. Nonetheless, the short-run behavior of inflation may be affected by a variety of non-monetary shocks. Since the first OPEC oil shock, economists have increasingly stressed the role of supply shocks in accounting for sudden (short-run) spikes and drops in the rate of inflation. However, identifying the exact channels through which supply shocks affect inflation turns out to be surprisingly hard. In fact, the classical theory states that industry specific supply shocks only affect relative prices, see for instance Friedman (1975).[1]

Ball and Mankiw (1995) offer a new and challenging explanation for the inflationary effects of supply shocks by introducing price stickiness into the analysis[2]. They argue that the classical dichotomy between relative and general price changes only holds under full flexibility of prices. Using a model in which prices respond only to large shocks, they show that the distribution of shocks across firms (sectors) determines if and to what extent the inflation rate is affected. More particularly, the general price level rises when the distribution of the firms' desired price changes is skewed to the right. Conversely, it decreases when the distribution is skewed to the left. The intuition is simple. Suppose the economy is hit by a negative supply shock. In this model this means the distribution of desired price changes is skewed to the right. Since firms only adjust prices to the new desired price level if the desired change is sufficiently large, positive skewness of desired price changes implies that large positive price changes are more likely to occur than large negative price changes. As a result, the effects of relative price increases on the general

[1] The following quotation of Friedman (1975), as published in Ball and Mankiw (1995), summarizes this view perfectly: "... it is essential to distinguish changes in *relative* prices from *absolute* prices. The special conditions that drove up the price of oil and food required purchasers to spend more on them, leaving them less to spend on other items. Did that not force other prices to go down or to rise less rapidly than otherwise? Why should the *average* level of prices be affected significantly by changes in the price of some things relative to others? ... .

[2] In a number of similar contributions oil prices were assumed to be flexible, while other prices were assumed rigid. In this setting an increase in the relative price of oil can raises the general price level (see for example Gordon, 1975).

price level outweigh the effects of relative price decreases. This induces positive rates of inflation.

Ball and Mankiw (1995) provide quite some empirical evidence in support of the link between inflation and the skewness of sectorial price changes on the basis of PPI data. Comparing prices in different US. cities, Debelle and Lamont (1997) also find a strong and robust positive correlation of inflation and intermarket relative price variability, as predicted by the Ball and Mankiw model. Apparently, the main qualitative predictions of the model (in terms of correlations between skewness of sectorial indices and the inflation rate) are in line with the empirical evidence.[3]

One theoretical drawback of the model is that it ignores interaction among price-setters. Although a possibly non-zero inflation rate results, firms do not take this inflation into account when deciding on the size and frequency of adjustments. This restrictive assumption is dropped by allowing for interaction among price-setters. In our setting, when firms anticipate changes in the rate of inflation, they adjust their desired prices accordingly, even if less than one-for-one. Hence, when agents expect supply shocks to be inflationary, they raise their prices by even more if they are in the upper tail of the desired price change distribution. In the lower tail of the distribution, firms lower their prices by less. The net effect is an even larger increase in the general price level.

Not surprisingly, this extended version of the model does a much better job at matching the stylized facts of US inflation. The inflationary effect of a negative supply shock turns out to be substantially larger when inflation expectations are introduced. For reasonable parametrizations, the inflationary effects of supply shocks in the no-interaction case (i.e. the Ball and Mankiw case) remain quite small and do not exceed 1% (see Ball and Mankiw, 1995, p. 171). This upper bound can be understood in the following way. Since supply shocks in this model explain primarily short run inflation, the relevant gauge for the upper bound is the standard deviation of the inflation innovations. Using Tables II and IIIA in

[3] In addition, the model has interesting theoretical implications. As it turns out, menu-cost models not only account for the real effects of nominal shocks; these models also explain the nominal (inflationary) effects of real shocks, as argued by Ball and Mankiw (1995).

Ball and Mankiw, the mean of inflation over the period 1948-1989 is 3.5% and the standard deviations of the inflation shocks (innovations) is about 3.97%.[4] As such, this model clearly is not capable of producing sufficient inflation to qualify as a valuable theory of short-run inflation. Introducing inflation expectations raises this upper bound considerably to about 6.5%. This result clearly adds some emprical relevance to the model's intuitive appeal in showing that it is at least capable of generating the right numbers. In theory, supply shocks can be the main force driving short-run inflation variability.

The remainder of the paper is organized in four sections. The second section contains an outline of the model and its underlying assumptions. We derive the rational expectations equilibrium inflation rate as a fixed point from the mapping of inflationary expectations to actual inflation. Using a number of propositions we characterize the properties of this equilibrium inflation rate. Section 3 compares the inflationary effects of supply shocks in the Ball and Mankiw benchmark model to the effects obtained in our setting. Our simulations illustrate that the inflationary effect is invariably larger than in the benchmark no-interaction case. Section 4 concludes by summarizing the main findings.

[4] The standard deviation of the inflation innovations was calculated as follows: the standard deviation of the inflation rate over 1948-1989 is 4.68%. In order to compute the standard deviation of inflation innovations, we use a AR(1) model for inflation: $\pi_t = \rho\pi_{t-1} + u_t$. Ball and Mankiw (1995) estimate ρ at 0.527 (see table IIIA). The standard deviation of inflation innovation hence is given by $\sigma_u = \left[(1-\rho^2)\sigma_\pi^2\right]^{1/2} =$ 3.97%.

2 Theoretical Model

We briefly outline the determinants of the firm's price-setting strategy in monopolistic competition framework. Blanchard and Kyotaki (1987) pioneered these models to analyze the effects of nominal rigidities in a general equilibrium setting.

2.1 Assumptions and set-up of the model

Considering an economy consisting of a continuum of industries, indexed by i, Ball and Romer (1989) derived, using a model in the vein of Blanchard and Kyotaki (1987), the desired price of a typical firm in industry i, $p^*_{i,t}$, as:

$$p^*_{i,t} = vm_t + (1-v)E_{t-1}(p_t) + w\theta_{i,t}, \tag{1}$$

where p_t denotes the general price level (in logs), m_t denotes the nominal money supply (in logs), and θ_i is an industry-specific shock.[5] The parameters v $(0 \leq v < 1)$ and w are a function of the elasticity of substitution and the elasticity of marginal disutility w.r.t. effort (Ball and Romer (1989), p. 182). Note that we implicitly assume that industry-specific shocks are observed before expectations about the general price level are formed.

Our analysis is static, as in Ball and Mankiw (1995). More specifically, we assume

[5]The desired price level p^* is the price charged by the firm if no nominal rigidities are present. The desired price depends on three factors. The first factor comprises real shocks (θ), warranting a change in the individual price relative to the general price level. The remaining two determinants, expected general price level and the money supply, enter due to the so-called aggregate demand externality, see Dornbusch and Fischer (1989). The connection between the desired price level, the money supply and expected general price level can be seen by rewriting (1) as follows:

$$p^* = Ep + (1-v)\left[m - Ep\right] + w\theta,$$

where $m - Ep$ denotes the expected real money balances. Disregarding the second term on the RHS, the optimal (individual) pricing rule ensures that the expected relative price equals the target relative price $w\theta$. So, a change in the general price level would be accompanied by an equivalent increase in the individual price (assuming $d\theta = 0$). However, there is a second effect which firms take into consideration, i.e. the effect of general price changes on real money balances. If the general price change is not met by an equivalent change in the money supply, real money balances are affected and the aggregate demand for goods will change. This demand externality therefore makes firms adjust prices also accordance to expected changes in the real money balances. An increase in the price level, not accompanied by an equivalent increase in the money stock, will only partially (i.e. a fraction $(1-v)$) be incorporated into the desired price level because of its negative effect on aggregate demand.

that (i) all industries are pricing optimally at the outset ($p^*_{i,t-1} = p_{i,t-1}$), (ii) the money supply is constant ($m_t = m_{t-1}$) and (iii) no shocks occurred before time t ($\theta_{i,t-1} = 0$). Under these assumptions, we can express the desired price change, $\Delta p^*_{i,t}$, as a function of expected inflation and the industry-specific shock in t : [6]

$$\Delta p^*_{i,t} = (1 - v)\pi^e_t + w\theta_{i,t}. \tag{2}$$

Although industries are modelled as homogeneous entities as far as shocks are concerned, firms within each industry are assumed to have different levels of menu costs, c_j, where the index j denotes a specific firm in an industry. More precisely, within each industry i, the distribution of $\sqrt{c_j}$ (across the different firms) is modeled by means of a continuous and monotonically increasing cumulative distribution function $G(.)$, which is assumed to be the same across industries. As such, the fraction of firms within each industry with menu costs smaller or equal to $\sqrt{c}$ is given by $G\left(\sqrt{c}\right)$.

Following Ball and Romer (1989) we assume that the profit function of firm j in industry i, $z_t(i,j)$ can be approximated by:

$$z_t(i,j)_t = -E_t\left[(\Delta p_{i,t} - \Delta p^*_{i,t})^2 - c_j\iota\right], \tag{3}$$

where $\Delta p_{i,t}$ denotes the firm's observed price change between t and $t-1$, and ι denotes a dummy variable taking the value 1 if the firm changes its price and 0 if it does not alter prices. In this one period model, a firm's change in price will equal the desired one, since menu costs are independent of the size of the price adjustment. The decision whether or not to change prices then depends on whether or not expected profits will be higher, after

[6] Note that equation (2) presents the pricing equation in absence of nominal rigidities. This pricing equation only differs from the pricing equation of Ball and Mankiw (1995) by the inclusion of expected inflation. There is ample econometric evidence that firms take the general inflation level into account in their individual pricing rules. For instance, Cecchetti (1986) performs a study of price adjustments in the newspaper market. The main finding of this paper is that the frequency of price adjustments increases significantly with the inflation rate. The frequency of price revisions doubled when inflation went form about 2% over the period 1953-1965 to almost 8% in the 1970's. This positive correlation between the frequency of price adjustments and the general inflation is also found for the economy as a whole, see Cecchetti (1985). These findings can be interpreted as supporting evidence for including the expected inflation in the pricing rule of individual firms.

taking into account the costs of price adjustment, than in the case of no adjustment. More formally, firm j in industry i will change prices if and only if:

$$\left|\Delta p^{*}_{i,t}\right| = |(1-v)\pi^{e} + w\theta_i| \geq \sqrt{c_j}. \tag{4}$$

Hence, the fraction of firms adjusting prices is given by $G\left(|(1-v)\pi^{e} + w\theta_i|\right)$ and consequently, the change in the industry $i's$ price index, denoted by π_i, is:

$$\pi_i = \left((1-v)\pi^{e} + w\theta_i\right) G\left(|(1-v)\pi^{e} + w\theta_i|\right). \tag{5}$$

Finally, aggregating over all industry price indices, we obtain the change in the general price level, π, as:

$$\pi = \int_{-\infty}^{+\infty} \left((1-v)\pi^{e} + w\theta\right) G\left(|(1-v)\pi^{e} + w\theta|\right) f(\theta) d\theta, \tag{6}$$

where aggregation is achieved by integrating over the density of industry specific shocks, $f\left(\theta_i\right)$. We assume the distribution of industry-specific shocks to be such that no inflation obtains if all firms adjust prices. This boils down to assuming that $\int \theta f\left(\theta\right) d\theta = \mu\left(\theta\right) = 0$. In case of incomplete price adjustment asymmetries in the distribution of shocks generate non-zero inflation even though the average of all shocks across industries is zero.

2.2 Equilibrium inflation with and without interaction

In their seminal article Ball and Mankiw (1995) considered the borderline case where $v = 1$, henceforth referred to as the no-interaction case. Under this assumption price-setters do not take into account the price-setting behavior of other sectors when determining the desired price change. The resulting inflation rate, as defined in (6), then reduces to:

$$\pi^{ni} = \int_{0}^{+\infty} \left(w\theta\right) G\left(w\theta\right) \left[f(\theta) - f(-\theta)\right] d\theta. \tag{7}$$

From equation (7), it is obvious that non-zero rates of inflation obtain if the distribution of industry-specific shocks and hence desired price changes is asymmetric ($f(\theta) \neq f(-\theta)$ for some $\theta \in [0, \infty)$). Note also that the effect of idiosyncratic shocks on the inflation rate depends on two elements: the asymmetry of the distribution of shocks across industries and the distribution of menu costs within each industry. One cannot be more explicit about the inflationary effects than simply noting that they will be non-zero without imposing further assumptions on both distributions .[7]

Since the main aim of this paper is to compare the inflationary effects of supply shocks in the no-interaction and the interaction case, the exact functional specifications of f and G are not a matter of concern. All results will be related to the no-interaction benchmark inflation rate, π^{ni}.

We now extend the Ball and Mankiw (1995) set-up by allowing for interaction among price-setters ($v < 1$). In this approach, expectations naturally play a crucial role. We derive a rational expectations equilibrium in which agents fully anticipate the inflationary effects of the shocks. The introduction of inflation expectations results in an increase of the sensitivity of the general price level to the skewness of desired price changes, as will be shown in section 3.

Note that in a rational expectations set-up, with agents knowing the complete distribution of shocks before decisions about changes in prices are to be made, realized inflation must equal expected inflation, i.e. $\pi = \pi^e$. Recall that the mapping from expectations to inflation is given by:

$$\pi = T(\pi^e) = \int_{-\infty}^{+\infty} \left((1-v)\pi^e + w\theta\right) G\left(|(1-v)\pi^e + w\theta|\right) f(\theta) d\theta, \tag{8}$$

where $T()$ is a continuous mapping from π^e to π. The equilibrium inflation rate therefore is given by $\pi = T(\pi^e) = T(\pi)$, i.e. the fixed point(s) of the $T()$ mapping. In proposition 1, we demonstrate the existence of an equilibrium inflation rate in the interaction case, i.e. there exists a π such that $\pi = T(\pi)$.

Proposition 1: *Let $f(.)$ and $G(.)$ be such that $\pi^{ni} \geq 0$, then there exists a $\pi \in R^+$*

[7] If, as in Ball and Mankiw (1995), we assume that $G(.)$ is exponentially distributed and the density of shocks is the skew-normal one, a one to one relation between inflation and skewness of shocks can be established. More specifically, the more positively skewed the latter distribution becomes, the stronger the inflationary effects of the supply shocks.

such that $\pi = T(\pi)$. *Analogously, let* $f(.)$ *and* $G(.)$ *be such that* $\pi^{ni} \leq 0$, *then there exists a* $\pi \in R^{-}$ *such that* $\pi = T(\pi)$.

Proof: See Appendix

Uniqueness could not be established in general. However, the simulation results reported in section 3 suggest that there is only one fixed point for a wide set of distribution functions.

Next, we evaluate the properties of the rational expectations equilibrium. First, note that zero-inflation is the unique fixed point when prices are fully flexible[8]. This result is merely a restatement of the classical dichotomy separating relative from absolute price changes under full flexibility of prices: the rate of inflation is unaffected by sectorial shocks. This claim is formalized in corollary 1.

Corollary 1: *When* $G() = 1$ *for all* θ *then* $\pi^e = \pi = 0$ *is the unique fixed point of the mapping* $T()$.

Proof: See Appendix.

Notice that this result is independent of the exact nature of the distribution of sectorial shocks. The asymmetry of the distribution of the shocks has no effect on the general price level as long as prices adjust instantaneously.

Second, in an environment with nominal rigidities, even when introducing expectations, inflation (still holding the money supply constant) is caused by the asymmetry of the distribution of shocks over the industries. Recall that firms subject to shocks in the upper tail of the $f()$ distribution raise prices, while firms in the lower tail lower prices. When this distribution is fully symmetric, the upper and lower tails have equal probability mass and the net effect on the general price level is zero, provided that agents expect zero-inflation ($\pi^e = 0$). Hence, zero-inflation is a rational expectations equilibrium. On the other hand, it is not optimal for agents to expect price stability when the distribution is asymmetric.

[8] Note that this will also be the case if the variance of the shocks is infinite.

Agents expecting zero-inflation will invariably be mistaken. So, in the asymmetric case, zero-inflation cannot be a rational expectations equilibrium. This result is formalized in proposition 2.

Proposition 2: *When the distribution is symmetric ($f(\theta) = f(-\theta)$ for all $\theta \in \mathbf{R}$), $\pi = 0$ constitutes a fixed point of the mapping $T()$. When the distribution is asymmetric, such that $\pi^{ni} \neq 0$, and $G() \neq 1$ for all $\theta \in \mathbf{R}$, $\pi = 0$ can be ruled out as a fixed point of the mapping $T()$.*

Proof: See Appendix

Third, we show that the inflation expectation effect adds to the skewness effect: in a rational expectations equilibrium the absolute value of the rate of (de-) inflation exceeds $|\pi^{ni}|$, the rate of inflation when inflation expectations are nil ($\pi^{ni} \equiv T(0)$).

Proposition 3: *If $\pi^{ni} > 0$, then any fixed point $y = T(y)$, $y \in R^+$ is such that: $y > \pi^{ni}$. If $\pi^{ni} < 0$, then any fixed point $y = T(y)$, $y \in R^-$ is such that: $y < \pi^{ni}$.*

Proof: See Appendix

Ball and Mankiw (1995) disregard interaction among price-setters by setting $v = 1$. This implies that individual prices do not respond to (expected) changes in the general price level. Recall that π^{ni} denotes the equilibrium rate of inflation when $v = 1$. Note that π^{ni} equals $T(0)$ (for any $v \in [0,1]$) , the rate of inflation that obtains when inflation expectations are nil. It follows from the previous proposition that introducing interaction among price-setters invariably raises equilibrium (de-) inflation when the distribution of shocks is asymmetric. This result is quite intuitive. Positive inflation expectations cause an increase in the proportion of firms raising their prices, while it decreases the proportion of firms lowering their prices. In addition, firms in the upper tail raise prices by more, while firms in the lower tails decrease prices by less. The net effect is an increase in the inflationary effect of the asymmetries relative to the Ball and Mankiw case. The size of this increase depends on the elasticity of individual desired prices w.r.t. the general price level $(1-v)$, as illustrated below.

Finally, we discuss the v-parameter. A simple transformation of v, $1-v$, can be interpreted as the elasticity of individual desired prices w.r.t. the general price level. As the sensitivity of individual prices to changes in the expected rate of inflation, $(1-v)$, increases, the equilibrium rate of (de-) inflation increases.

Proposition 4: *For* $\pi^e \in [0,\infty)$, $dT(\pi^e)/d(1-v) \geq 0$. *For* $\pi^e \in (\infty, 0]$, $dT(\pi^e)/d(1-v) \leq 0$. *Hence, for* $\pi^{ni} > 0$ *the fixed point* $y = T(y) \in [0,\infty)$ *increases in* $(1-v)$. *Conversely, when* $\pi^{ni} < 0$, *the fixed point* $y = T(y) \in (-\infty, 0]$ *decreases as* $(1-v)$ *decreases.*

Proof: The proof is obvious and has been omitted.

3 Simulations

To assess the quantitative importance of these results, some numerical calculations are presented that show how much interaction increases the responsiveness of inflation to the skewness of the distribution of idiosyncratic price shocks relative to the no-interaction case. To facilitate the comparison, we chose to replicate the Ball-Mankiw (1995, p. 170) results by picking the same functions and parameter values. An exponential distribution was chosen for the distribution of menu costs:

$$G(\sqrt{c}) = 1 - \exp(-a\sqrt{c}), \tag{9}$$

where a was set equal to seven. This implies the mean value of $\sqrt{c}$ is $\frac{1}{7} \approx 15\%$.[9] This 15% inaction range for deviations of actual from desired prices corresponds more of less with the empirical evidence on price-adjustments (Blinder, 1991).

[9] $E(\sqrt{c}) = \int_0^\infty \sqrt{c}\frac{dG(\sqrt{c})}{d\sqrt{c}}d\sqrt{c} = \int_0^\infty a\sqrt{c}\exp\{-a\sqrt{c}\}\, d\sqrt{c} = \frac{1}{a}$

Following Ball and Mankiw, we chose the skew-normal distribution for $f()$ which reduces to the normal distribution as the skewness tends to zero (see Azzalini, 1985). Obviously we modelled the random variable such that the mean equals zero. Hence, in the perfect flexibility case, $G() = 1$, no inflation would occur.

Below we examine the effects of variations in the skewness and standard deviation of θ (denoted $\sigma(\theta)$ and $k(\theta)$) on the moments of industry price changes, π_i, as defined in equation (5). The moments of industry price changes are denoted μ_p, σ_p and k_p respectively. Recall that μ_p is in fact the rate of inflation in the economy while σ_p and k_p denote the standard deviation and the skewness of the changes in the sectorial price indices, respectively.

In addition, we report results for different values of the general price level elasticity $(1 - v)$. When $v = 1$, individual desired prices do not respond to anticipated changes in the overall price level. This is the case considered by Ball and Mankiw. The results corresponding to this case are reported in the first column of every table. The results for $v = 1$ are nearly identical to those reported in Ball and Mankiw (1995, p. 171).[10] As v decreases, individual prices react more strongly to anticipated changes in the rate of inflation.

INSERT TABLES 1-5

The results of the simulation exercise can be found in tables 1-5. Each table reports moments for sectorial price changes for a different value of $k(\theta)$, the skewness parameter of the distribution of the supply shock, θ. Allowing $k(\theta)$ to increase while fixing v and $\sigma(\theta)$, we find that the rate of inflation (μ_p) increases monotonically, as emphasized by Ball and Mankiw. This holds uniformly for all values of v. To verify this claim, compare the different tables, for fixed values of $\sigma(\theta)$ and v. Evidently, the introduction of interaction among price-setters does not change this pattern. As the upper tail becomes larger relative to the lower tail, the rate of inflation increases as more firms start to raise prices. In addition, the skewness of actual sectorial price changes (k_p) increases as the skewness of desired price

[10] The w parameter was normalised to 1.

changes increases $(k(\theta))$. Hence, the relation between inflation and skewness of supply shocks translates into a positive relation between inflation and skewness of sectorial price changes, a fact which has been verified by Ball and Mankiw. Our extension, however, shows that for a given skewness level the inflationary effects will be larger than in the no-interaction case. Note that the standard deviation of industry price changes, σ_p, is not affected by variations in the skewness of shocks $(k(\theta))$.

Next, consider the effects of the standard deviation of these shocks $(\sigma(\theta))$. Examining different rows of Tables 1-5, we find that a larger dispersion of supply shocks, $\sigma(\theta)$, implies a larger dispersion of sectorial price changes, σ_p, as is to be expected. More interestingly, for small values of $\sigma(\theta)$, the effect of an increase in $\sigma(\theta)$ on μ_p is positive: an increase in $\sigma(\theta)$ initially tends to induce higher average inflation. The increase in the variance magnifies the asymmetry of the tails and, hence, raises the net effect on the price level. As $\sigma(\theta)$ increases beyond 0.25, however, the relation between $\sigma(\theta)$ and μ_p reverses. Recall that zero inflation obtains as $\sigma(\theta) \to \infty$ (see footnote 5). All firms adjust and prices are fully flexible. Hence, inflation does not rise monotonically in the variance of relative price shocks, $\sigma(\theta)$.

To see this, consider Figures 1 and 2. These figures display π^e on the horizontal axis and $T(\pi^e) - \pi^e$ on the vertical axis. For $k(\theta) = 0.8$ and $v = 0.5$, we illustrate the non-monotonic effects of increases in $\sigma(\theta)$. The intersection of the lines with the vertical axis correspond to the Ball and Mankiw rate of inflation, $\pi^{ni} = \pi^0 = T(0)$. The intersection with the horizontal axis corresponds to our rational expectations equilibrium, i.e. $\pi = T(\pi)$. It is obvious form these figures that our fixed point solution $y = T(y)$ invariably exceeds π^{ni}, as claimed in Proposition 3. Figure 1 shows that an increase in $\sigma(\theta)$ shifts the $T-$mapping upwards, rasing both π^{ni} and y, for values of $\sigma(\theta)$ in the $[0, 0.25]$ range. Figure 2 illustrates that this relation reverses once $\sigma(\theta)$ increases beyond this threshold level. The amount of inflation which can be generated by (skewed) relative price shocks is therefore clearly constrained. Our extension raises this upper bound significantly by introducing the effects of inflation expectations.

Finally, we mention the effects of the v-parameter; $(1 - v)$ is the elasticity of individual desired prices w.r.t. to the general price level. Looking across the columns in tables 1-5, we note that decreases in v uniformly raise μ_p, the rate of inflation, as claimed in Proposition 4. While variations in v do not have a noticeable effect on σ_p, decreases in v lower the skewness of industry price changes, k_p. Figure 4 gives a graphical account of the effects of v, plotting π^e on the horizontal axis and $T(\pi^e) - \pi^e$ on the vertical axis. Note that the $y = T(y)$ equilibrium rate of inflation decreases monotonically in v. We conclude this section by mentioning that within a wide range of values for inflation expectations there is only one fixed point (see figure 4). Figure 4 shows that within the range of 0 to 40% there is only one intersection of the $y - T(y)$ function, indicating that there is only one fixed point to be found in this range. Additional experiments where the range was increased to over 100% did not alter this conclusion.

4 Conclusion

This paper extends the Ball and Mankiw (1995) model. In their model short-run inflation is the outcome of idiosyncratic price shocks asymmetrically buffeting various industries in the economy. If only a fraction of firms within a given industry adjust prices, relative price shocks turn out to be (de-) inflationary. Our paper introduces interaction among price setters, a feature which was not present in Ball and Mankiw's original model. Firms are aware of the inflationary effects of the supply shock and use this information to determine the optimal price response to the supply shock.

As in Ball and Mankiw, we find a positive correlation between inflation and the skewness of industry price changes. For reasonable parameter values, their version of the model yields an upper bound on the size of inflation innovations of about 1%. Introducing inflation expectations raises this upper bound to well over 5%. This increase is crucial given that the standard deviation of the post-war US inflation innovations is approximately 3.97%. If supply-shock driven theories of inflation are to explain the observed short-run inflation variability, accounting for inflation expectations seems essential.

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Appendix

Proof of Proposition 1: Let $\{\pi_n^e\}$ denote an increasing sequence. Then

$$\{f_n\} = \{((1-v)\pi_n^e + w\theta))\, G\left(|(1-v)\pi_n^e + w\theta|\right)\}$$

is a monotone increasing sequence of functions converging to $f_n = (1-v)\pi_n^e + w\theta$ for π_n^e large enough. From the monotone convergence theorem:

$$\lim_{\pi^e \to \infty} (1-v)\pi^e = \lim_{n\to\infty} T(\pi_n^e),$$

which implies that there exists a finite $\overline{x} \in \Re^+$ such that $T(\overline{x}) = (1-v)\overline{x} + \varepsilon$, where ε is arbitrarily small. Consider the case where $\pi^{ni} \equiv T\,(0) \geq 0$. Since $T(.)$ is a continuous function on $[0, \overline{x}]$, it follows that there exists a fixed point, $x = T(x)$, on $[0, \overline{x}]$ since $T(0) \geq 0$ and $T(\overline{x}) < \overline{x}$. This concludes the existence proof.

Proof of Corollary 1: Note that actual inflation in the full-adjustment case is :

$$\begin{aligned}\pi &= \int_{-\infty}^{+\infty} ((1-v)\pi^e + w\theta)\, f(\theta)d\theta \\ &= (1-v)\pi^e,\end{aligned}$$

which implies that $\pi = \pi^e = 0$ is the only rational expectations equilibrium.

Proof of Proposition 2: The first claim in Proposition 2 can easily be verified by redefining the integration interval:

$$\begin{aligned}
\pi &= T(\pi^e) \\
&= (1-v)\pi^e \int_0^{+\infty} \left[G\left(|(1-v)\pi^e + w\theta|\right) f(\theta) + G\left(|w\theta - (1-v)\pi^e|\right) f(-\theta)\right] d\theta + \\
&\quad \int_0^{+\infty} (w\theta) \left[G\left(|(1-v)\pi^e + w\theta|\right) f(\theta) - G\left(|w\theta - (1-v)\pi^e|\right) f(-\theta)\right] d\theta
\end{aligned} \tag{A.1}$$

$$\begin{aligned}
&= (1-v)\pi^e \int_0^{+\infty} \left[G\left(|(1-v)\pi^e + w\theta|\right) + G\left(|w\theta - (1-v)\pi^e|\right)\right] f(\theta) d\theta + \\
&\quad \int_0^{+\infty} (w\theta) \left[G\left(|(1-v)\pi^e + w\theta|\right) - G\left(|w\theta - (1-v)\pi^e|\right)\right] f(\theta) d\theta,
\end{aligned}$$

where we have used symmetry of $f()$ $(f(\theta) = f(-\theta))$ in the second equality. This demonstrates that 0 is a fixed point. Verify by setting $\pi^e = 0$ in the last equation $(A.1)$.

Next, we prove the second part of Proposition 2. Return to the first equation in $(A.1)$ and evaluate this expression in $\pi^e = 0$. Let π^0 denote $T(0)$:

$$\pi^0 = T(0) = \int_0^{+\infty} (w\theta)\, G\,(w\theta) \left[f(\theta) - f(-\theta)\right] d\theta,$$

where π^0 is in general non-zero since $f()$ is not symmetric. Hence, $\pi^0 \neq \pi^e = 0$.

Proof of Proposition 3:

In this proof we consider the case where $\pi^{ni} = \pi^0 = T(0) > 0$. In case there is interaction equilibrium inflation rate, x, has to solve $x = T(x)$:

$$x = T(x) = \int_{-\infty}^{+\infty} ((1-v)x + w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta.$$

Or, equivalently:

$$x = \frac{\int_{-\infty}^{+\infty} (w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta}{1-(1-v)\int_{-\infty}^{+\infty} G(|(1-v)x + w\theta|)\, f(\theta)d\theta}.$$

Since $G(.)$ is bounded by 0 and 1, it follows that the denominator will be smaller or equal to 1. That is, for $0 \leq v \leq 1$: $v \leq 1-(1-v)\int_{-\infty}^{+\infty} G(|(1-v)x + w\theta|)\, f(\theta)d\theta \leq 1$.

Next, consider the numerator:

$$\begin{aligned}\int_{-\infty}^{+\infty} (w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta &= \int_{0}^{+\infty} (w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta + \\ &\quad \int_{-\infty}^{0} (w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta.\end{aligned}$$

Note that for the second term on the LHS we have that:

$$\int_{-\infty}^{0} (w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta = \int_{0}^{+\infty} w(-\theta)\, G(|-(1-v)x + w\theta|)\, f(-\theta)d\theta$$

such that the numerator : $\int_{-\infty}^{+\infty} (w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta$ can be rewritten as:

$$\int_{0}^{+\infty} (w\theta)\, \{G(|(1-v)x + w\theta|)\, f(\theta) - G(|(1-v)x + w\theta|)\, f(-\theta)\}\, d\theta.$$

Consider the class of positive fixed points, i.e. $x > 0$. Then: $G(|(1-v)x + w\theta|)\, f(\theta) > G(|w\theta|)\, f(\theta)$ and $G(|-(1-v)x + w\theta|)\, f(-\theta) < G(|w\theta|)\, f(-\theta)$ since $G(.)$ is a continuous cumulative distribution function and hence monotonically increases in its argument.

Therefore we have that the numerator

$$\int_{-\infty}^{+\infty} (w\theta)\, G(|(1-v)x + w\theta|)\, f(\theta)d\theta > \int_{0}^{+\infty} (w\theta)\, G(|w\theta|)\, \{f(\theta) - f(-\theta)\}\, d\theta \equiv T(0).$$

Finally, since the denominator is smaller or equal to 1 we have that for $\pi^{ni} = T(0) > 0$, there exists a fixed point x such that $x > \pi^{ni} = T(0)$.

This concludes the proof. Analogously, when $\pi^{ni} < 0$, the equilibrium rate of deflation is larger then the rate of deflation in the absence of inflation expectations (i.e. $v = 1$). The proof is, mutatis mutandi, identical.

Tables:

Table 1: **Moments of industry price changes and inflation (skewness of supply shock=0.2)**

$k(\theta)$	v	1	0.9	0.5	0.1
0.2	$\sigma(\theta)$	0.05			
	μ_p	0.0005	0.0005	0.0006	0.0008
	σ_p	0.0218	0.0218	0.0218	0.0218
	k_p	0.642	0.638	0.624	0.60
	$\sigma(\theta)$	0.10			
0.2	μ_p	0.0011	0.0012	0.0016	0.0026
	σ_p	0.065	0.065	0.065	0.065
	k_p	0.445	0.441	0.423	0.376
0.2	$\sigma(\theta)$	0.15			
	μ_p	0.0015	0.0016	0.0024	0.0048
	σ_p	0.117	0.117	0.117	0.117
	k_p	0.346	0.342	0.321	0.260
0.2	$\sigma(\theta)$	0.20			
	μ_p	0.0017	0.0018	0.0029	0.0068
	σ_p	0.170	0.170	0.170	0.170
	k_p	0.291	0.288	0.270	0.200
0.2	$\sigma(\theta)$	0.25			
	μ_p	0.0017	0.0018	0.0030	0.0083
	σ_p	0.225	0.225	0.225	0.225
	k_p	0.259	0.257	0.242	0.170

Table 2: **Moments of industry price changes and inflation (skewness of supply shock=0.4)**

$k(\theta)$	v	1	0.9	0.5	0.1
0.4	$\sigma(\theta)$	0.05			
	μ_p	0.0010	0.0010	0.0013	0.0016
	σ_p	0.022	0.022	0.022	0.022
	k_p	1.231	1.224	1.195	1.154
	$\sigma(\theta)$	0.1			
0.4	μ_p	0.0023	0.0025	0.0034	0.0054
	σ_p	0.066	0.066	0.066	0.066
	k_p	0.865	0.858	0.816	0.727
0.4	$\sigma(\theta)$	0.15			
	μ_p	0.0031	0.0034	0.0050	0.0100
	σ_p	0.117	0.117	0.117	0.117
	k_p	0.679	0.672	0.630	0.504
0.4	$\sigma(\theta)$	0.2			
	μ_p	0.0035	0.0037	0.0060	0.0142
	σ_p	0.171	0.171	0.171	0.171
	k_p	0.576	0.570	0.532	0.385
0.4	$\sigma(\theta)$	0.25			
	μ_p	0.0035	0.0038	0.0063	0.017
	σ_p	0.225	0.225	0.225	0.225
	k_p	0.515	0.511	0.478	0.334

Table 3: **Moments of industry price changes and inflation (skewness of supply shock=0.6)**

$k(\theta)$	v	1	0.9	0.5	0.1
0.6	$\sigma(\theta)$	0.05			
	μ_p	0.0015	0.0016	0.0020	0.0025
	σ_p	0.022	0.022	0.022	0.022
	k_p	1.778	1.768	1.722	1.653
	$\sigma(\theta)$	0.10			
0.6	μ_p	0.0036	0.0038	0.0053	0.0084
	σ_p	0.066	0.066	0.066	0.066
	k_p	1.270	1.258	1.188	1.043
0.6	$\sigma(\theta)$	0.15			
	μ_p	0.0049	0.0053	0.0079	0.0155
	σ_p	0.118	0.118	0.117	0.118
	k_p	1.006	0.996	0.926	0.723
0.6	$\sigma(\theta)$	0.2			
	μ_p	0.0054	0.0059	0.0094	0.0223
	σ_p	0.170	0.170	0.170	0.170
	k_p	0.858	0.849	0.788	0.552
0.6	$\sigma(\theta)$	0.25			
	μ_p	0.0055	0.0060	0.0100	0.0277
	σ_p	0.225	0.225	0.225	0.225
	k_p	0.770	0.762	0.711	0.466

Table 4: **Moments of industry price changes and inflation (skewness of supply shock=0.8)**

$k(\theta)$	v	1	0.9	0.5	0.1
0.8	$\sigma(\theta)$	0.05			
	μ_p	0.0021	0.0022	0.0027	0.0034
	σ_p	0.022	0.022	0.022	0.022
	k_p	2.270	2.259	2.188	2.086
	$\sigma(\theta)$	0.10			
0.8	μ_p	0.0049	0.0053	0.0072	0.0115
	σ_p	0.066	0.066	0.066	0.066
	k_p	1.657	1.642	1.672	1.340
0.8	$\sigma(\theta)$	0.15			
	μ_p	0.0067	0.0073	0.0110	0.0216
	σ_p	0.117	0.117	0.117	0.117
	k_p	1.330	1.315	1.220	0.925
0.8	$\sigma(\theta)$	0.2			
	μ_p	0.0075	0.0082	0.0130	0.0313
	σ_p	0.170	0.170	0.170	0.170
	k_p	1.143	1.130	1.045	0.701
0.8	$\sigma(\theta)$	0.25			
	μ_p	0.0076	0.0083	0.0139	0.0392
	σ_p	0.224	0.224	0.224	0.224
	k_p	1.029	1.019	0.945	0.587

Table 5: **Moments of industry price changes and inflation (skewness of supply shock=0.99)**

$k(\theta)$	v	1	0.9	0.5	0.1
0.99	$\sigma(\theta)$	0.05			
	μ_p	0.0029	0.0031	0.0037	0.0047
	σ_p	0.022	0.022	0.022	0.022
	k_p	2.767	2.750	2.665	2.520
	$\sigma(\theta)$	0.10			
0.99	μ_p	0.0071	0.0076	0.0105	0.0164
	σ_p	0.065	0.065	0.065	0.065
	k_p	2.081	2.059	1.920	1.608
0.99	$\sigma(\theta)$	0.15			
	μ_p	0.010	0.011	0.0165	0.032
	σ_p	0.115	0.115	0.115	0.117
	k_p	1.697	1.675	1.526	1.065
0.99	$\sigma(\theta)$	0.20			
	μ_p	0.012	0.013	0.020	0.048
	σ_p	0.167	0.167	0.167	0.171
	k_p	1.470	1.449	1.314	0.747
0.99	$\sigma(\theta)$	0.25			
	μ_p	0.0130	0.0142	0.0235	0.0646
	σ_p	0.220	0.220	0.220	0.226
	k_p	1.325	1.307	1.177	0.562

Table 6: **Monetary contractions and sensitivity of industry prices to inflation expectations.**

v	$\widehat{m}$	$T(\pi^e, 0)$
1	-0.0085	0.0076
0.9	-0.0093	0.0083
0.8	-0.0105	0.0093
0.6	-0.0141	0.0119
0.5	-0.0169	0.0139
0.4	-0.0211	0.0166
0.2	-0.0424	0.0270
0.1	-0.0845	0.0392

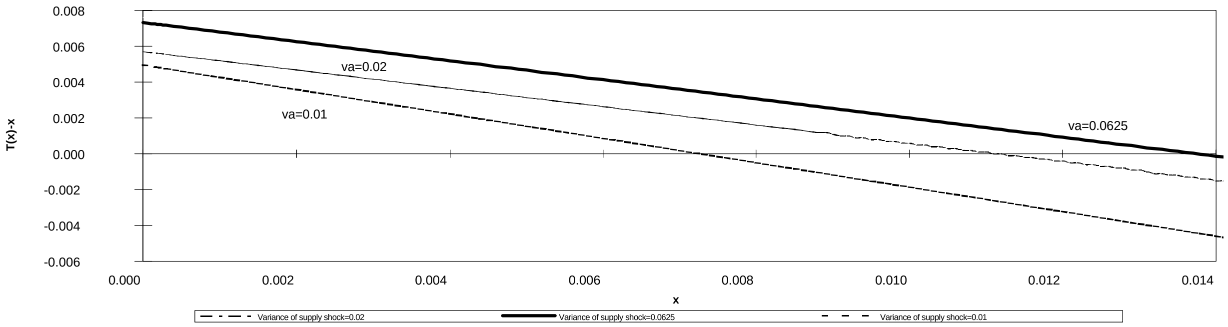

Figure 1: The relationship between inflation and variance of supply shocks part 1.

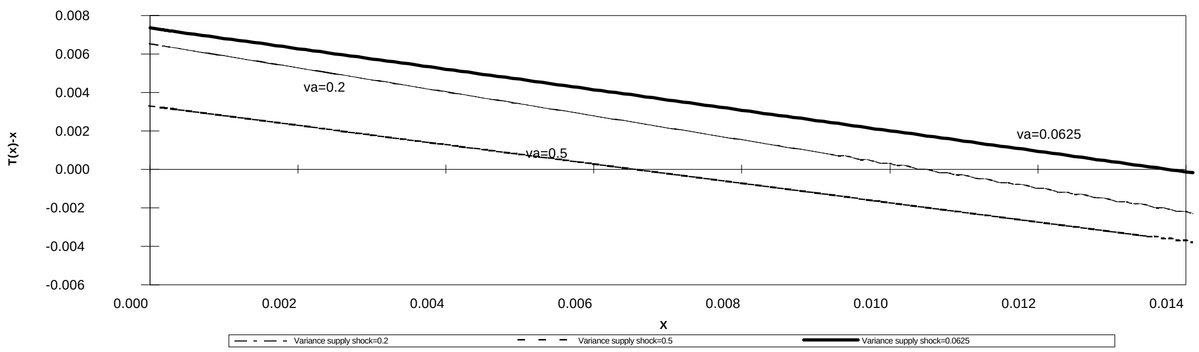

Figure 2: The relationship between inflation and variance of supply shocks part 2.

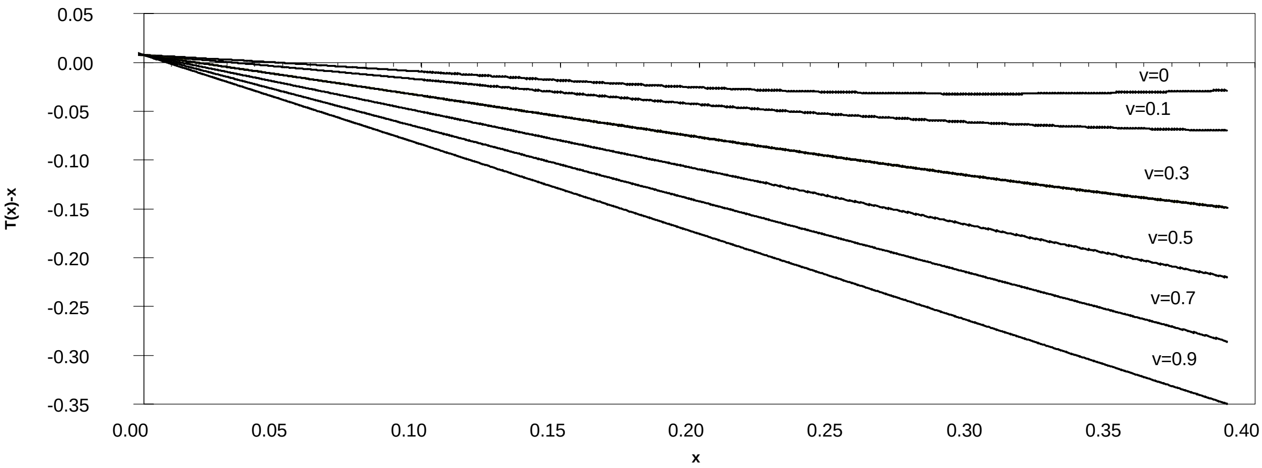

Figure 3: Inflation and senstivity of industry price to inflation expectations.

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