Asymmetric Price Adjustment: Micro-foundations and Macroeconomic Implications

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Abstract

We present a simple menu cost model which explains the finding that firms are more likely to adjust prices upward than downward. Asymmetric adjustment to shocks arises naturally, even without trend inflation, from the desire of firms to keep industry prices as high as is sustainable and the non-convexity due to menu costs. It implies that aggregate demand shocks have asymmetric effects — negative shocks are reduce output, whereas positive shocks are inflationary. We examine the implications of asymmetric adjustment for equilibrium output and the optimal inflation rate.

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1 INTRODUCTION

Prices are more likely to rise than to fall. This asymmetric response to shocks appears to hold in a number of markets, including gasoline ((Karrenbrock (1991), Borenstein, Camerer and Gilbert (1997)), bank deposits (Neumark and Sharpe (1992), Jackson (1997)), and agricultural products ((Karrenbrock (1991)). More generalized evidence comes from Peltzman's (2000) study of over 240 markets. He finds that asymmetries are pervasive, substantial and durable, in producer goods as well as consumer goods, and exist in low inflation as well as high inflation periods. Buckle and Carlson (2000) also find generalized evidence of such asymmetries from survey data. These asymmetries also apply at the level of price indices — Verbrugge (2002) confirms this for most disaggregated price indices in the US, and in a cross-country study (Verbrugge, 1998), finds evidence of asymmetry for almost all countries.

The macroeconomic significance of such an asymmetry in adjustment has often been stressed. Tobin (1972) suggested that asymmetries were important in price as well as wage setting, and argued that this lead to aggregate demand shocks having asymmetric effects. That is, positive aggregate demand shocks would raise prices while negative demand shocks cause output contraction. Such asymmetric demand effects are documented by Cover (1992), DeLong and Summers (1988) and Sichel (1993). Asymmetries have gained attention in the current low inflation environment in OECD countries, with some economists arguing that low inflation may be a mixed blessing. By preventing relative price adjustments, low inflation exacerbates the effects of negative demand shocks, and reduces the equilibrium level of output (see DeLong and Summers (1988) and Akerlof, Dickens and Perry (1996)). A contrary view, (see Lucas (2000)), is that there remain significant welfare gains from reducing inflation even further towards zero. Asymmetric adjustment to cost shocks can also result in first order output losses from international commodity price fluctuations, thus making the stabilization of prices desirable (Kanbur and Vines, 1986).

To understand the empirical evidence and to evaluate these contrary macroeconomic views, it is imperative that we understand the underlying reasons for asymmetric nominal rigidities. If we understand the foundations of such asymmetries, then only can one evaluate the impact of changes in the environment, such as changes in trend inflation. However, there has been little in terms of microfoundations for the assumption for asymmetric nominal rigidities. If prices are set by optimizing agents, then one should, in general, expect a symmetric response to shocks. Asymmetries can arise if utility or profit functions are not quadratic (Kimball, 1989), but there seems little reason for systematic deviations in one direction or the other.

It is recognized that positive trend inflation may be a reason for asymmetric adjustment (see Tsiddon (1993) and Ball and Mankiw (1994)). Positive trend inflation, aggravates positive shocks while mitigating negative shocks, so that asymmetric price adjustment to shocks arises naturally. However, since inflation is the only cause for asymmetry, adjustment becomes symmetric as trend inflation falls to zero, and the asymmetry is reversed with trend deflation. Thus one would not expect aggregate demand shocks to have asymmetric effects when inflation is low, and the optimal inflation rate in indeed zero. Ball and Mankiw conclude that since inflation is the only cause of asymmetry in adjustment by rational agents, Tobin's arguments do not seem to be valid, at least when agents are behaving optimally. Nevertheless, trend inflation seems to be an inadequate explanation for asymmetric adjustment. Peltzman shows that the asymmetry is as pronounced in the period 1982-1996, when trend inflation was below 2%. DeLong and Summers (1988) also find that asymmetric output effects of demand shocks are present (and indeed, stronger) during the Great Depression, when the price trend was deflationary. Peltzman's comment, that asymmetric adjustment "poses a challenge to theory", thus seems a valid one.

This paper proposes a simple argument for asymmetric adjustment even in the absence of inflation. We argue that in the real world, the notion of an *industry* — a group of firms producing closely substitutable products — plays an important role. Introducing the notion of an industry into standard imperfect competition models has two immediate implications:

1. The existence of competitor firms in the same industry reduces equilibrium prices, as compared to a situation where the industry consists of only one firm. Firms in the industry would be better off if they could collude on higher prices, but this impossible to sustain.

2. A firm finds it important to keep its price in line with its competitors in the same industry — the prices charged by firms outside its industry are less important.

Point (2) above implies that if the industry is subjected to a shock, and if the firm must incur a menu cost to adjust price, its optimal choice depends upon whether other firms in the industry are adjusting or not. This gives rise to multiple equilibria in the adjustment decision at the industry level — there is an equilibrium where all firms in the industry adjust, and another equilibrium where no firm adjusts. We argue that firms are likely to coordinate upon the equilibrium which they collectively prefer, which in the context of point (1) above, is the equilibrium in which prices are higher. This corresponds to raising prices in response to a positive shock, but not cutting prices when the shock is negative. Thus asymmetric adjustment arises naturally in this model as an industry response to shocks so as keep prices as high as possible.

We show that asymmetric price adjustment implies asymmetric adjustment of output to demand shocks, in line with the empirical evidence. We also analyze the effects of such asymmetric adjustment in a dynamic context, and show that long run equilibrium output is lower than the static level. The effects of inflation on equilibrium output are also examined.

The organization of the rest of this paper is as follows. We begin in section 2 by setting out a simple general equilibrium model with imperfect competition and examine the static equilibrium in this model. Section 3 considers the effects of a one-time shock when firms face menu costs of price adjustment. Section 3 considers a full dynamic model, and the effects of asymmetric adjustment on equilibrium output, and section 4 considers the effects of inflation in this economy. The final section reviews some of the related literature and concludes.

2 THE MODEL

The model we develop is a simple generalization of the standard model of an imperfectly competitive macro-economy, as set out for example in Blanchard and Fisher (1988). We allow each industry to consist of many producers, rather than just one. [1]There is a continuum of industries distributed uniformly on the unit interval. In each industry, there is a continuum of producer-consumers also distributed uniformly on the unit interval. Index industries by upper case letters, and producers within an industry by lower case letters, so that producer r in industry S has index rS, where $r \in [0,1]$ and $S \in [0,1]$. The utility of the typical producer-consumer depends upon an index of her total consumption, C_{rS}, and is decreasing in the output she produces, Y_{rS}, in the following manner

$$U_{rS} = C_{rS} - \left(\frac{\gamma - 1}{\gamma\beta}\right) \Lambda_J \left(Y_{rS}\right)^{\beta} \tag{1}$$

β is the elasticity of the marginal disutility of labor plus one, and is assumed to be greater than one. Λ_J is an industry level productivity parameter

[1]This more general model nests the standard model as a special case, and may be useful in analyzing other macroeconomic issues as well — Bhaskar (2002) uses this to provide an explanation for staggered price setting.

and $\frac{\gamma-1}{\gamma\beta}$ is an inessential constant. The index of consumption, C_{rS}, is composed as follows. First, the consumption of products of individual producers in any particular industry, say industry J, are aggregated CES fashion, giving rise to C_{rS}^{J}, the index of the total consumption of goods from industry J, by producer rS. These industry aggregates are then aggregated to give the index of total consumption.

$$C_{rS}^{J} = \left\{ \int\limits_{i\in[0,1]} \left(C_{rS}^{iJ} \right)^{(\gamma-1)/\gamma} di \right\}^{\gamma/(\gamma-1)} \tag{2}$$

$$C_{rS} = \left\{ \int\limits_{J\in[0,1]} \left(C_{rS}^{J} \right)^{(\theta-1)/\theta} dJ \right\}^{\theta/(\theta-1)} \tag{3}$$

Note that C_{rS}^{iJ} is the consumption of the good produced by producer i in industry J by consumer rS. The key parameters of our model are γ and θ. γ is the elasticity of substitution between products which are produced by the same industry, while θ is the elasticity of substitution between products produced by different industries. Our key assumption is that $\gamma > \theta$, so that the notion of an industry makes sense. Note that if $\gamma = \theta$, our model is identical to the standard models of Blanchard and Fischer (1988) so that the standard model is a special case of ours. We assume that $\gamma > 1$, to ensure the existence of a solution to the producer's maximization problem.

The utility function implies that the industry price index, P^{J}, and output index, Y^{J},are given by

$$P^{J} = \left\{ \int\limits_{i\in[0,1]} \left(P^{iJ} \right)^{(1-\gamma)} di \right\}^{1/(1-\gamma)} \tag{4}$$

$$Y^{J} = \frac{1}{P^{J}} \int\limits_{i\in[0,1]} \left(P^{iJ} Y^{iJ} \right) di \tag{5}$$

The aggregate price level, P, and aggregate output index, Y, are given by

$$P = \left\{ \int\limits_{J\in[0,1]} \left(P^{J} \right)^{(1-\theta)} dJ \right\}^{1/(1-\theta)} \tag{6}$$

$$Y = \frac{1}{P} \int\limits_{J\in[0,1]} \left(P^{J} Y^{J} \right) dJ \tag{7}$$

To allow nominal shocks to play a role, we assume that the relation between money balances and spending on goods is given by

$$Y = \frac{M}{P} \tag{8}$$

The above equations imply that the demand faced by producer iJ is given by

$$Y^{iJ} = \left(\frac{P^{iJ}}{P^J}\right)^{-\gamma} \left(\frac{P^J}{P}\right)^{-\theta} \left(\frac{M}{P}\right) \tag{9}$$

We solve first for the static optimal price of the individual producer with index iJ. Such a producer takes the industry price P^J, the aggregate price P, and the money supply M as given and chooses price P^{iJ} to maximize utility. We shall use the corresponding lower case letters to denote the natural logarithms of variables (e.g. p is $\ln P$). The optimal price is given by

$$p^*_{iJ} = \alpha p^J + \alpha' p + (1 - \alpha - \alpha')m + \hat{\alpha}\lambda_J \tag{10}$$

where

$$\alpha = \frac{(\gamma - \theta)(\beta - 1)}{1 + \gamma(\beta - 1)} \tag{11}$$

$$\alpha' = \frac{1 + (\theta - 1)(\beta - 1)}{1 + \gamma(\beta - 1)} \tag{12}$$

$$\hat{\alpha} = \frac{1}{1 + \gamma(\beta - 1)} \tag{13}$$

Note that if $\gamma > \theta$, $\alpha > 0$, so that the firm's optimal price is an increasing function of the industry price. That is, strategic complementarity at the industry level follows immediately from the assumption that the elasticity of substitution is greater for products within the industry than across the industry. On the other hand, α' can be either positive or negative, since we do not need to assume that the industry elasticity of demand θ exceeds one (an assumption which is necessary in the standard model). In what follows, we shall often simplify by assuming that $\alpha' = 0$.

2.1 Equilibrium

Let us now assume that all industries have the same productivity parameter λ_J, which is normalized to zero. That is, we assume that there are no industry specific shocks at this point. To see that a symmetric equilibrium exists, note that if each producer consumer sets her price equal to m, then equation (10) will be satisfied. This is indeed the only equilibrium in this (static) model. Since each firm is of measure zero, every firm in industry J faces the same industry price (even if individual firms choose different prices) and the same aggregate price. By equation (10), every firm in industry J must therefore choose the same price. We can therefore re-write (10) for the equilibrium industry price level as

$$p_J^* = \frac{\alpha'}{1-\alpha}p + \frac{(1-\alpha-\alpha')}{1-\alpha}m \tag{14}$$

Since each industry faces the same aggregate price level and m, it follows that the equilibrium industry price is identical for every industry. Thus we have verified that equilibrium in this (static) model exists, is unique and is symmetric.

Let us now consider how the utility of the producer-consumer varies with the prices and money in this economy. The indirect utility function of the producer consumer can be written as

$$V = V(m-p, p_{iJ} - p_{iJ}^*, p_J - p) \tag{15}$$

The partial derivatives of the utility function, evaluated at the equilibrium, are given by

$$\frac{\partial V}{\partial(m-p)} = \frac{1}{\gamma} > 0 \tag{16}$$

$$\frac{\partial V}{\partial(p_J - p)} = \frac{\gamma-\theta}{\gamma} > 0 \tag{17}$$

Note that a higher industry price (p_J) has a positive effect on producer utility, since the partial derivative in 17 is positive. Since the derivative with respect to the firms own price is zero at the optimum, all firms in the industry would be better off if they could coordinate upon a higher price. This however is not sustainable as an equilibrium.

This simple static model provides a framework within validates the Calmfors-Driffill (1988) argument on the relation between the extent of centralization of wage bargaining and aggregate output/employment. Due to monopolistic competition, equilibrium in this model is clearly inefficient, with prices being too high and output being too low. This inefficiency is exacerbated if firms within the industry collude in setting prices. However, if additionally, if there is centralization and the enforcement of a cooperative arrangement across the entire economy, prices would be lower and welfare increased —

this can be seen by noting that in this case the effect of a marginal reduction in prices is positive and given by 16.

Let us now allow for different industries to have different values of λ_J. Assume that λ is independently and identically distributed across firms, and has mean zero and is distributed with a density g. We approximate the aggregate price level by

$$p = \int_0^1 p_J dj \tag{18}$$

We claim that it is an equilibrium for each firm in industry J to set the same price which is equal to

$$p_J = m + \frac{\hat{\alpha}}{1-\alpha}\lambda_J \tag{19}$$

To verify this, note that aggregate price is given by

$$p = m + \frac{\hat{\alpha}}{1-\alpha}\int \lambda g(\lambda) d\lambda = m \tag{20}$$

where the last step follows from the fact that λ has zero mean. It is now immediate that in this equilibrium, each firm satisfies the price setting rule 10.

To summarize: equilibrium output does not depend upon the distribution of productivity shocks, in the absence of menu costs.

3 Menu Costs and Asymmetric Adjustment

Let us now consider the adjustment of prices in this economy to a one-time shock in the presence of menu costs, i.e. a fixed cost c of adjusting price, given that the initial situation is one where all producers are choosing price optimally. Let us normalize the initial values of the money supply and of the input shock λ to zero, so that all firms in all industries are choosing an initial price of zero. Our arguments are similar in the case of real shock or a nominal shock, and it is economical to discuss them together. Let us simplify the exposition by assuming that $\alpha' = 0$, so that the firm's optimal price does not depend upon the aggregate price level. Thus the firm's optimal price, absent any menu cost, can be re-written as

$$p_{iJ}^* = \alpha p^J + (1-\alpha)m + \hat{\alpha}\lambda_J \tag{21}$$

Defining $\varepsilon_J = (1-\alpha)m + \hat{\alpha}\lambda_J$, the firm's optimal price is given by

$$p_{iJ}^{*} = \begin{cases} \varepsilon_J \text{ if } D_J = 0 \\ \frac{\varepsilon_J}{1-\alpha} \text{ if } D_J = 1 \end{cases} \tag{22}$$

where $D_J \in \{0, 1\}$ is the proportion of firms in the industry which adjust price. Thus the extent to which a firm's optimal price changes with a shock is greater if $D_J = 1$, i.e. if its industry adjusts price, as compared to the situation where the industry does not adjust.

Let us now consider the loss to the individual firm from not adjusting. Since initial prices are chosen optimally, the envelope theorem implies that the loss to each producer from inertia is second order in ε, so that inertia is uniquely optimal if $|\varepsilon|$ is sufficiently small relative to c (see Akerlof and Yellen (1985) and Mankiw (1985)). On the other hand, if $|\varepsilon|$ is very large, it is uniquely optimal for each firm in industry J to fully adjust. Our interest is in the case where $|\varepsilon|$ is of intermediate size, since in this case the firm's optimal decision depends upon the adjustment decisions of the others. The loss of the individual producer from not adjusting, depends upon $|\varepsilon|$, and upon the fraction of firms in the industry who adjust. For our purposes, it suffices to consider the two extreme cases. If all other firms in the industry do not adjust price, we denote the loss function by $L^N(.)$. If all firms in the industry adjust price, we denote the loss function by $L^A(.)$. Using a second-order Taylor approximation, the loss functions are given by:

$$L^N(\varepsilon) = \frac{1}{2}\varepsilon^2 \tag{23}$$

$$L^A(\varepsilon) = \frac{1}{2}\left(\frac{1}{1-\alpha}\right)^2 \varepsilon^2 \tag{24}$$

Inspection of the above expressions shows that for any values of ε, $L^A(\varepsilon) > L^N(\varepsilon)$. This follows since α is positive, due to the greater elasticity of substitution within the industry (γ) as compared to the substitution elasticity between industries θ. Thus for any given shock, whether due to productivity or nominal demand, the loss is greater if other firms in the industry adjust as compared to the situation where the industry does not adjust. This implies that there are multiple equilibria in adjustment – for values of $|\varepsilon|$ of intermediate size, there exists an equilibrium where all firms in the industry adjust, as well as an equilibrium where no firms in the industry adjust. Figure 1 graphs the loss as a function of ε. As one can see from this figure, if $|\varepsilon|$ lies between $\underline{\varepsilon}$ and $\bar{\varepsilon}$, then the firm's loss is greater than the menu cost if other firm's are adjusting, but smaller than the menu cost if other firms in the industry are not adjusting. Thus one has multiple equilibria in the adjustment decision at the industry level.

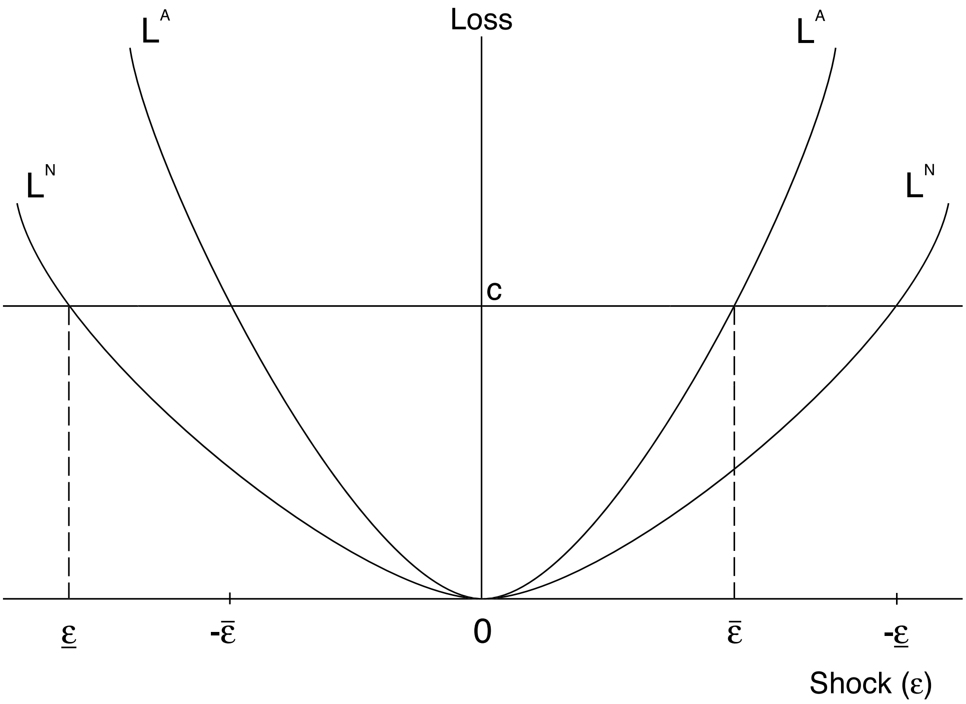

Fig. 1: Loss from non-adjustment to shocks.

In the presence of multiple equilibria, we may ask, which equilibrium do the firms prefer? We may expect that firms in the industry will be able to coordinate upon the better equilibria, since this coordination of expectations is only required at industry level. It turns out that the answer will depend upon whether the input shock is positive or negative. For a positive shock, the firms prefer the equilibrium where they adjust, while for a negative shock, they prefer the equilibrium where they do not adjust. The reason for this is straightforward. As we have seen from equation (17), producers in the industry prefer higher prices, as compared to the equilibrium price. When ε is positive, adjustment gives rise to the higher industry price, while when ε is negative, non-adjustment gives the higher industry price. More precisely, we shall assume that firms in the industry coordinate upon *best* (payoff maximizing) equilibrium in adjustment decisions. Such coordination of adjustment decisions gives rise to asymmetric adjustment thresholds. The adjustment threshold for positive shocks is $\bar{\varepsilon}$, while the adjustment threshold for negative shocks is $\underline{\varepsilon}$.

$$\underline{\varepsilon} = -\sqrt{2c} \tag{25}$$

$$\bar{\varepsilon} = (1-\alpha)\sqrt{2c} \tag{26}$$

Clearly $-\underline{\varepsilon} > \bar{\varepsilon}$, and the magnitude of asymmetry is measured by the difference in the absolute value of the two thresholds, $-\underline{\varepsilon} - \bar{\varepsilon}$. Asymmetry is greater the larger is α, which in turn depends on how large γ is relative to θ, i,.e. the larger elasticity of substitution within industry as compared to across industries. [2] The asymmetry is pronounced, even for moderate values of γ. As we shall see from our simulations, if $\gamma = 5$ (or greater), and shocks are normally distributed with standard deviation 0.1, then there is virtually no adjustment to negative shocks, while 80% of positive shocks meet with adjustment.[3] Thus under plausible parameter values, we are able to explain the empirical evidence on asymmetric adjustment, such as the findings of Peltzman (2000), and the other studies cited in the introduction.

Let us now discuss Peltzman's findings in more detail. Peltzman documents the incidence of asymmetric adjustment to input shocks in a diverse range of industries. Peltzman explores the suggestion that collusion may be responsible for asymmetries, and finds the incidence of asymmetry is not greater in more concentrated industries.[4] Our theory does not rely upon the number of firms being few or the market being concentrated in order to explain asymmetric adjustment. Indeed, our formal model shows that such asymmetries are possible in industries with a continuum of firms, each of whom serves a negligible fraction of the market. What is the relation between asymmetric adjustment and collusion? Our explanation for asymmetric adjustment is based on inability of firms to collude fully. If firms in an industry were able to collude, they would choose the monopoly price (with a markup on marginal cost equal to $\frac{\theta}{\theta-1}$, based on the industry elasticity of demand, rather than the markup of $\frac{\gamma}{\gamma-1}$ which is based on the firm level elasticity of demand). If such collusion is sustainable, firms have no incentive to seek higher prices, and hence the rationale for asymmetric adjustment disappears. As against this, one might argue that industries with fewer firms may be not be able to collude, but maybe better placed to coordinate upon asymmetric adjustment rules. This might be a countervailing reason for expecting asymmetries to be more likely in industries with fewer firms.

What are the macroeconomic implications of asymmetric adjustment? In our model, aggregate output is given by the simple quantity relation, $y = m - p$. Thus output effects are inversely related to the extent of price

[2] If $\gamma = \theta$, the two loss functions L^A and L^N collapse to a single one, and the asymmetry vanishes. In this case, the behavior of firm's own industry becomes irrelevant because the individual industry is of measure zero in the aggregate economy.

[3] Table 2 reports these simulations, which are for nominal shocks, but a similar feature applies to real shocks.

[4] On the other hand, Neumark and Sharpe (1992) find that asymmetric adjustment of bank deposit interest rates is more likely in more concentrated markets.

adjustment. Let us first consider the effects of sectoral shocks. We assume that there is no monetary shock ($m = 0$), and consider productivity shocks across industries which have zero mean. Thus we let λ_J be independently and identically distributed across industries, with mean zero, so that there is no aggregate productivity shock. We shall also assume that g,the probability density function of the random variable λ, satisfies the following assumption.

Distributional Assumption:$g(x) = g(-x)$ so that g is symmetric around zero. $g(x)$ is strictly decreasing for $x > 0$.

The new price level is given by

$$\begin{aligned} p &= \frac{\hat{\alpha}}{1-\alpha}\left(\int_{\bar{\lambda}(0)}^{\infty} \lambda g(\lambda) d\lambda + \int_{-\infty}^{\underline{\lambda}(0)} \lambda g(\lambda) d\lambda\right) \\ &= \frac{\hat{\alpha}}{1-\alpha}\int_{\bar{\lambda}(0)}^{-\underline{\lambda}(0)} \lambda g(\lambda) d\lambda > 0 \end{aligned} \tag{27}$$

where $\bar{\lambda}(0) = (1-\alpha)\sqrt{2c}/\hat{\alpha}$ and $\underline{\lambda}(0) = -\sqrt{2c}/\hat{\alpha}$. In the first expression, the first term in brackets above is positive while the second term is negative. Since the thresholds are asymmetric, while $g(.)$ is symmetric, the net effect of sectoral shocks is to raise the aggregate price level. Thus output falls due to sectoral shocks. This is in contrast to the case without menu costs, where sectoral shocks have no effect on output.

Let us now consider the effects of nominal demand shocks, in the presence of sectoral shocks. Each industry faces a sector specific shock, λ_J. In addition, all industries face a common nominal shock whereby the money supply changes from zero to m. The aggregate price level is now given by

$$p = m[1 - \Pr(N)] - \frac{\hat{\alpha}}{1-\alpha}\mu(\bar{\lambda}, \underline{\lambda}) \tag{28}$$

where $\Pr(N)$ is the probability of non-adjustment, i.e.

$$\Pr(N) = G(\bar{\lambda}(m)) - G(\underline{\lambda}(m))$$

$$\mu(\bar{\lambda}, \underline{\lambda}) = \int_{\underline{\lambda}(m)}^{\bar{\lambda}(m)} \lambda g(\lambda) d\lambda$$

The thresholds are given by

$$\bar{\lambda}(m) = \frac{-\sqrt{2c} - (1-\alpha)m}{\hat{\alpha}} \tag{29}$$

$$\underline{\lambda}(m) = \frac{(1-\alpha)(\sqrt{2c} - m)}{\hat{\alpha}} \tag{30}$$

We may now see why positive shocks to money have smaller (absolute) output effects than negative shocks. Negative shocks make the adjustment thresholds ($\bar{\lambda}(m)$ and $\underline{\lambda}(m)$) more symmetric, while positive shocks to m make the adjustment thresholds more asymmetric. Since the size of the interval of non-adjustment, $\bar{\lambda}(m) - \underline{\lambda}(m)$, is invariant to changes in m, the probability of inertia $\Pr(N)$ rises with negative shocks and falls with positive shocks. Furthermore, μ is negative due to asymmetric adjustment, and becomes larger in absolute value when adjustment becomes more asymmetric. Thus for both these reasons, positive money shocks have larger price effects than negative ones. This asymmetry has the immediate implication that fluctuations on nominal aggregate demand have asymmetric real effects. The absolute size of the output effects of a boom will be smaller than the output effect of a recession of the same magnitude. This can be seen in table 1 below which reports values of the level of output and the degree of nominal inertia for various values of the nominal shock. These simulations are based on the following parameter values, which are empirically plausible. Marginal costs are assumed to be quadratic, so that $\beta = 2$. The value of θ is set so that the effect of the aggregate price on the individual firm's price is zero, i..e. $\alpha' = 0$. The elasticity of demand of the individual firm (γ) is set to 5, which corresponds to a mark-up on marginal cost which is 20% of the product price. The menu cost is set to 0.001, which corresponds to 0.1% of equilibrium revenues. We assume that shocks are normally distributed with mean zero and standard deviation 0.1.

We begin first by reporting that when $\Delta m = 0$, output is 3.5% below the static equilibrium level. Thus asymmetric output adjustment to real shocks reduces equilibrium output, as suggested by DeLong and Summers (1988). However, we do not emphasize this result, since we shall see in the following sections that it needs to be modified in the dynamic context, where firms take into account their own asymmetric future behavior when choosing their initial price. Accordingly, the output levels in table one are reported *relative* to the output level for $\Delta m = 0$. Thus we see that negative shocks have larger absolute effects on output as compared to positive shocks. Nominal inertia declines with positive shocks, and increases for negative shocks. Indeed, the level of nominal inertia is a decreasing function of Δm, except when Δm is negative and large in magnitude.

$\Delta m(\%)$	-20	-10	-5	-2	0	2	5	10	20
$\Delta y(\%)$	-8.5	-5.7	-2.8	-1.0	0	0.9	1.9	3.0	3.5
$\Pr(N)$	0.75	0.88	0.81	0.73	0.67	0.60	0.48	0.29	0.06

Table 1

4 Asymmetries in A Dynamic Context

We now consider the implications of asymmetric adjustment in a two period model. We adopt a set up which involves a mix of time dependent and state dependent pricing, as in Ball and Mankiw (1994). One-half of all industries are "odd", while the remaining are "even". If a firm belongs to an odd industry, it adjusts its price for sure in every odd period. In addition, it can also adjust price in an even period, and this adjustment incurs a menu cost. Thus it will choose to adjust in the even period if the shock is sufficiently large relative to the menu cost. Thus in any period, one half of the industries will be adjusting for sure, while the other half may or may not adjust, depending upon the shock. This set up has the virtue of combining essential elements of state dependent pricing (the adjustment decision for odd firms in even periods is state dependent) with analytical tractability. Our focus is on the long run effects of asymmetric adjustment on equilibrium output.

Let us consider a firm in a typical "odd" industry. We may consider nominal as well as productivity shocks, but for simplicity we focus on the former, and assume that $\lambda = 0$ for all industries. Normalize the initial value of the money supply (in period one), in logs, to zero. In period two, the money supply equals m. m is a random variable with density function f and distribution function F, and satisfies the distributional assumption.

Consider the final period, period two. Let us assume that all firms in the industry have chosen the period zero price equal to x. Note that x need not be equal to zero, even though the money supply equals zero in period zero. Indeed, as we shall see, the equilibrium value of x will be negative.

Following the discussion in previous subsection, we assume that the industry follows an asymmetric adjustment rule. That is, the firms in the industry will adjust their price if $m \leq \underline{m}$ or if $m \geq \bar{m}$, but will not adjust their price for values of m lying in the interval $(\underline{m}, \bar{m})$. These thresholds are given by

$$\underline{m} = x - \frac{\sqrt{2c}}{1-\alpha} \tag{31}$$

$$\bar{m} = x + \sqrt{2c} \tag{32}$$

Let us now solve the equilibrium value of x, which will also determine the adjustment thresholds in the second period. Let x_i denote the price set by firm i in period one, and let x denote the aggregate industry price in period one. The firm sets x_i in order to minimize the discounted sum of its loss (and adjustment cost) over the two periods, where δ is the discount factor.

As before, we assume $\alpha' = 0$. The total loss over two periods, as a function of the first period price is given by

$$L(x_i, x) = \frac{1}{2}(x_i - \alpha x)^2 + \delta \int_{\underline{m}}^{\bar{m}} \frac{1}{2}[x_i - \alpha x - (1-\alpha)m]^2 f(m)dm + \delta[1 - \Pr(N))]c \tag{33}$$

where $\Pr(N) = F(\bar{m}) - F(\underline{m})$ is the probability that there is no price adjustment in period two. This expression assumes that the firm sets the same adjustment thresholds $\underline{m}, \bar{m}$ as the industry even if it chooses x_i different from x. Under this assumption, the thresholds do not vary with x_i, and the first order condition for minimizing the overall loss is given by

$$L'(x_i, x) = (x_i - \alpha x) + \delta \int_{\underline{m}}^{\bar{m}} [x_i - \alpha x - (1-\alpha)m] f(m)dm = 0 \tag{34}$$

In the appendix we show that this expression remains valid even if we allow for variation in thresholds. That is, a version of the envelope theorem applies also in our context, where the thresholds are determined as an equilibrium phenomenon, rather than by individual optimization alone.

In a symmetric equilibrium $x_i = x$, which implies

$$x == \frac{\delta \mu(\underline{m}, \bar{m})}{1 + \delta \Pr(N)} \tag{35}$$

where $\mu(\underline{m}, \bar{m}) = \int_{\underline{m}}^{\bar{m}} m f(m)dm$. Since f is symmetric, $\mu(\underline{m}, \bar{m})$ vanishes unless the thresholds are asymmetric. However, due to the asymmetry in adjustment, $\mu < 0$. It follows that $x < 0$, i.e. the initial price is lower than the money supply.

The fact that $x < 0$ accentuates the asymmetry in adjustment, as can be seen by examining the expression for the thresholds, $\underline{m}$ and $\bar{m}$.

We conclude therefore that with asymmetric thresholds, the firm chooses a price which is on average higher than the money supply in period two, but a price lower than the money supply in period one.

We now turn to the output effects of asymmetric adjustment. Since half the industries adjust in any period, the equilibrium level of output in this economy is given by average value of money relative to prices $(m - p)$ over both periods. Denoting average output by y, we gave

$$y = \frac{1}{2}\left(-x + \int_{\underline{m}}^{\bar{m}} (m - x) f(m)dm\right) \tag{36}$$

On simplifying this reduces to

$$y = \frac{\mu(\underline{m}, \bar{m})(1-\delta)}{2(1+\delta \Pr(N)} < 0 \tag{37}$$

That is, although prices are below m_t in the initial period, and above m_t in the final period due to asymmetric adjustment, on average they will be too high, and thus output will be below its static level of zero. The reason for this is straightforward. Firms choose prices which are below their static optimal price in the initial period, since they expect adjustment to be asymmetric in the future. I.e. they know that if they do not adjust, then on average prices will be too high relative to m in the final period. This provides them with an incentive to reduce prices below the static optimum, but due to discounting, they do not reduce them enough. Nevertheless, the effects of equilibrium output are likely to be much smaller than the static one period model of the previous section indicated. We shall see that this is indeed the case in the following section.

How are overall industry profits affected by asymmetric adjustment? Recall that asymmetric adjustment is adopted as a response, which keeps industry profits as high as possible, in the period of adjustment. Thus it must raise industry profits in period two, the period in which adjustment is an option. However, we have seen that it reduces prices in period one, and must therefore reduce industry profits in period one. The overall first order effect on discounted profits, evaluated at period one is given by

$$\frac{\gamma - \theta}{\gamma} \left(x(1 + \delta \Pr(N) - \delta \mu(\underline{m}, \bar{m}) \right) = 0 \tag{38}$$

Thus asymmetric adjustment cannot raise profits from period one's point of view, although it does raise it from the point of view of period two. The positive effects on period two profits are precisely offset by the negative effects on period one profits. Thus the firms could as well play an equilibrium with symmetric adjustment, with no first order difference in their profits. Nevertheless, when it comes to period two, it is collectively optimal for firms in the industry to pursue asymmetric adjustment, since bygones are bygones. Thus the unique renegotiation proof equilibrium in this two period game is one with maximal asymmetric adjustment. Indeed, for any finite horizon, the unique renegotiation proof equilibrium is the one with maximal asymmetric adjustment.

The Cyclical Behavior of Price-Cost Margins

Our dynamic pricing model provides a reason why recessions raise price-cost margins. Consider a negative money shock in an even period. Since only some odd industries will be adjusting price, this money shock will have negative output effects, and thus demand will contract for all firms. Furthermore, for the firms which do not adjust price, marginal costs decline with the output contraction, and thus the price cost margin rises in the recession.. Since demand contracts overall, the firms which are adjusting price will also face lower profits and reduced cash flow. If credit markets are imperfect and internal finance an important consideration, this will raise the effective real interest rate, i..e reduce δ. Thus firms which are adjusting price will choose higher prices, i.e. prices closer to those which maximize single period profits. Thus real prices will rise and the output contraction will be greater. Conversely, with a positive money shock, output will expand and the price cost margin will decline, both due to nominal rigidity, and due to the relaxation of credit constraints.

This argument for why credit constraints result in a counter-cyclical movement in margins is similar to the explanation which involves customer markets (e.g.. Greenwald et. al. (1984), Gottfries (1989), Klemperer (1995), and Chevalier and Sharfstein (1996). In customer markets, prices involve an investment decision. Similarly, in a menu cost model, since prices today may persist tomorrow, there is an investment element to the pricing decision. Thus the evidence in favor of customer market models (e.g.. Chevalier and Sharfstein, 1996) also applies to our menu cost model.[5]

5 Inflation

We now consider the implications of trend inflation. Let the money supply in period one, $\tilde{m}$ be now given by $m+\pi$, where m denotes the money shock and π is the trend rate of inflation. As before, we assume that m is distributed symmetrically with density f. The adjustment thresholds are now given by

$$\underline{m} = x - \pi - \frac{\sqrt{2c}}{1-\alpha} \tag{39}$$

$$\bar{m} = x - \pi + \sqrt{2c} \tag{40}$$

where these thresholds apply to m, i.e. the firm adjusts price if $m \notin (\underline{m}, \bar{m})$.

Let us now consider the implications of inflation, i.e. a positive value of π. Let us assume for the moment that any change in inflation π will affect x less than one for one, i.e. $\frac{\partial x}{\partial \pi} < 1$. Thus under this assumption, positive

[5] In the absence of credit constraints, the customer market model can result in either pro or counter cyclical markups (Klemperer, 1995).

inflation will *increase* the asymmetry in adjustment since $\bar{m}$ and $\underline{m}$ both fall. Note also that the size of the interval of non-adjustment $(\underline{m}, \bar{m})$ is invariant with respect to changes in π. The effect on the probability of non-adjustment is given by

$$\frac{d\,\Pr(N)}{d\pi} = \left(\frac{\partial x}{\partial \pi} - 1\right)[f(\bar{m}) - f(\underline{m})] < 0 \tag{41}$$

Under the distributional assumption, $f(\bar{m}) > f(\underline{m})$, which implies that inertia declines with inflation, as a consequence of adjustment becoming more asymmetric.

Similarly, we can define μ as before. The effect on μ is given by

$$\frac{d\mu}{d\pi} = \left(\frac{\partial x}{\partial \pi} - 1\right)(\bar{m}f(\bar{m}) - \underline{m}f(\underline{m})) < 0 \tag{42}$$

Let us now consider the effect of inflation upon initial prices. Let δ denote the real discount rate, i.e. $\delta = 1/(1+r)$ where r is the real interest rate. Thus the optimal value of x satisfies

$$x = \frac{\delta[\mu(\underline{m}, \bar{m}) + \pi\,\Pr(N)]}{1 + \delta\,\Pr(N)} \tag{43}$$

Differentiating this expression, we find

$$\frac{dx}{d\pi} = \frac{\delta\Omega}{1 + \delta\Omega} \tag{44}$$

where Ω is given by

$$\Omega(\pi) = [\Pr(N) - f(\bar{m})\bar{m} + f(\underline{m})\underline{m}] - [f(\bar{m}) - f(\underline{m})](\pi - x) \tag{45}$$

Note that the first term in Ω is strictly positive, due to the distributional assumption. Although we cannot show that Ω is always positive for all values of inflation, simulations suggest that this is the case in a large range.

Let us now consider the effect of inflation on period two prices. The average level of period two prices relative to money is given by

$$z = \int_{\underline{m}}^{\bar{m}} (x - \pi - m) f(m) dm = \Pr(N)(x - \pi) - \mu \tag{46}$$

Hence

$$\frac{dz}{d\pi} = -\left(1 - \frac{dx}{d\pi}\right)\Omega \tag{47}$$

Aggregating across odd and even industries, the average level output in the economy is given by

$$y = \frac{1}{2}\left(-x + \int_{\underline{m}}^{\bar{m}} (\pi + m - x) f(m) dm\right) \tag{48}$$

The derivative of this with respect to inflation is given by

$$\frac{dy}{d\pi} = \frac{\Omega(1-\delta)}{2(1+\delta\Omega)} \tag{49}$$

which is positive as long as $\Omega > 0$.We now do some simulations in order to investigate the effects of changes in inflation. We choose parameter values as in our previous simulation. The discount factor δ is set at 0.9. We assume that m is normally distributed with mean zero and standard deviation 0.1. Since industry specific supply shocks and money supply shocks play a similar role in our model, we should really think of these shocks as the sum of the two types of shock — as Peltzman documents, there is considerable variability in industry supply shocks. Table 2 reports our results for different values of the inflation rate. Let us focus first on case of zero inflation, which is at the middle of the table. Note that there is significant asymmetry in adjustment — a 2% positive shock results in adjustment, whereas the threshold for a negative shock is more than ten times larger at -29%. In consequence, the initial price x is 2.3% below the static equilibrium value. Equilibrium output in the economy is negative, and about 0.1% lower than the static equilibrium value. In other words, asymmetric adjustment causes an output loss of about 0.1%.

$\pi(\%)$	-20	-10	-4	-2	0	2	4	10	20
$\underline{m}$	-0.16	-0.22	-0.26	-0.28	-0.29	-0.31	-0.32	-0.37	-0.47
$\bar{m}$	0.16	0.09	0.05	0.04	0.02	0.01	-0.01	-0.06	-0.16
$\Pr(N)$	0.88	0.80	0.69	0.64	0.59	0.53	0.47	0.28	0.06
μ	0.000	-0.023	-0.034	-0.036	-0.038	-0.039	-0.040	0.033	-0.012
x	-0.089	-0.054	-0.034	-0.028	-0.023	-0.018	-0.013	-0.004	0.000
$y(\%)$	-0.5	-0.3	-0.19	-0.16	-0.13	-0.10	-0.07	-0.02	0.00

Table 2

Let us now consider the effects of inflation. As inflation rises, the asymmetry in adjustment is accentuated, and the probability of inertia declines, reflecting this. Output rises gradually, till at 20% inflation it is equal to (approximately) the static equilibrium level. With deflation, the asymmetry in adjustment is reduced, and indeed vanishes at -20%. This increasing symmetry is accompanied by greater nominal inertia. Output falls with deflation, to -0.5% below the static equilibrium level when $\pi = -20\%$. Thus we find that inflation has a monotone effect on nominal inertia and on equilibrium output.

We therefore find that inflation raises output, and mitigates the effects of asymmetric price adjustment. Nevertheless, the effect does not seem too large. At zero inflation, output is 0.13% below the static equilibrium level. This is similar in magnitude to the menu cost of 0.001. The utility loss due to reduced output can be computed and is approximately 0.0003, i.e. about one-third of the menu cost. By raising inflation to 20% one can eliminate this output loss, but at the cost of increasing price adjustment. Thus it seems unlikely that for these parameter values, raising inflation substantially to increase output is a useful strategy. On the other hand, by raising inflation to 4%, one can recoup approximately one-half of the output loss due to asymmetric adjustment. These numbers also suggest that deflation is costly in terms of output.[6]

Our findings have relevance to measures of the welfare costs of inflation — Lucas (2000) provides a comprehensive discussion. These welfare costs arise since nominal interest rates provide socially inappropriate incentives for consumes to economize on money holdings. Lucas assumes that the real interest rate equals 3%, with the nominal rate being equal to the sum of the real rate and the inflation rate. The evidence suggests that there are major welfare gains from reducing nominal rates from 10% to 3%, by reducing inflation to zero. However, there is some uncertainty about the size of the welfare gain from reducing nominal rates to zero, via trend deflation — some specifications suggesting a similar large gain, while other specifications imply a modest effect. In the light of this discussion, our analysis suggests that a moderate negative output effect from reducing inflation towards zero needs to be taken into account. The output loss from trend deflation seems to be larger, thus further qualifying Lucas's conclusions.

6 Conclusions

We have set out a simple model of imperfect competition where asymmetric adjustment to nominal shocks emerges naturally, even in the absence of

[6] In this context, we should note that menu cost models suggest that inflation can increase welfare by reducing firm's monopoly power, in a non-stochastic environment (see Benabou (1992) and Diamond (1993)). Diamond reports that deflation is also effective in increasing welfare.

trend inflation, which is one explanation for asymmetric adjustment (Ball and Mankiw (1994) and Tsiddon (1993)). Firms in an industry would like to have higher prices, but competition prevents them from sustaining this. Asymmetric adjustment to shocks is an equilibrium which permits such higher prices on average. Such asymmetric rigidities mean that negative demand shocks have larger effects than positive ones, and also imply that equilibrium output is on average smaller. We now discuss some of the related literature.

Ball and Romer's (1991) were the first to show the possibility of multiple equilibria in the context of the standard model of monopolistic competition, where each industry consists of a single firm. If there are aggregate strategic complementarities in price setting, so that the optimal industry price is an increasing function of the aggregate price level, there can be multiple equilibria in adjustment decisions for intermediate values of shocks. Ball and Romer do not explore the possibility of asymmetric adjustment in this context – this is natural, since multiple equilibria only arise at the level of the aggregate economy, it is unrealistic to expect that agents will be able to coordinate their decisions at this level.[7] Indeed, their focus is on coordination failure, in contrast to the present paper which argues that coordination can emerge more easily at industry level. In contrast to standard models of multiple equilibria, which suggest that "anything is possible", our argument is based on systematically *selecting* a unique equilibrium, and seeing how the properties of the selected equilibrium varies with changes in the environment such as trend inflation.

Driscoll and Ito (1998) consider the implications of collusion, in the context of the standard model. If all firms in the economy collude, they would do so by reducing prices rather than by raising them, in order mitigate the aggregate demand externality. They also show that if only partial collusion is sustainable, this may result in asymmetric price adjustment. In our view, sustaining collusion at an economy wide level requires rather stringent informational assumptions If any firm is negligible, individual prices will have no effect on the aggregate price, and sustaining collusion requires that each individual firm's price is observed by all other firms in the economy. Bennett and La Manna (2001) provide an argument for the reverse asymmetry, where prices are more flexible downwards, based on a combination of Bertrand competition with Stackelberg price leadership.

Our focus in this paper has entirely been on price adjustment, since it is likely that entirely different considerations apply to wage setting behavior.

[7]Indeed, if coordination was possible at the aggregate level, one should expect the reverse asymmetry, since at the aggregate level prices are too high rather than being too low.

Bewley's interview study (1999) finds that factors of morale and efficiency wage arguments are an important reason for the reluctance of employers to cut wages. Our analysis suggests employers may take into account their own future inability to cut wages, thus setting wages lower than they would otherwise do.

A number of papers also analyze the implications of the current low inflation environment, and suggest that this may reduce equilibrium output. Akerlof, Dickens and Perry (1999) argue that low inflation is not incorporated in wage setting, thus producing a long run inflation-unemployment trade-off at low rates of inflation. Holden (2001) argues that the legal basis of wage contracts in Europe gives rise to downward nominal wage rigidity and adverse equilibrium employment effects.

7 Appendix

We show that the first order condition for minimizing the loss (equation 34) remains valid at the symmetric equilibrium when we allow the thresholds to vary with the choice of x_i. Consider x_i in the neighborhood of x, where $x_i < x$. In this case, since $\bar{m}$ is the smallest (absolute) value of the shock such that adjustment is an equilibrium, and since $\bar{m} - x_i$ is larger than $\bar{m} - x$, it remains optimal for the firm to not vary its upper threshold. Similarly, since $\underline{m}$ is the largest absolute value of the shock such that adjustment is an equilibrium, $x_i - \underline{m}$ is smaller than $x - \underline{m}$, it remains optimal for the firm to not vary its lower threshold. Thus the left hand derivative of the loss function evaluated at $x_i = x$ is indeed given by equation 34.

Consider next the case where $x_i > x$. In this case, the firm will indeed find it optimal to vary both its thresholds with x_i, and these are given by

$$\underline{m}_i = x_i - \frac{\sqrt{2c}}{1-\alpha} \tag{50}$$

$$\bar{m}_i = x_i + \sqrt{2c} \tag{51}$$

Thus the loss function differs from that given in the text by the term

$$\delta \int_{\bar{m}}^{\bar{m}_i} \{\frac{1}{2}[x_i - \alpha x - (1-\alpha)m]^2 - c\} f(m)dm - \delta \int_{\underline{m}}^{\underline{m}_i} \{\frac{1}{2}[x_i - \alpha x - (1-\alpha)m]^2 - c\} f(m)dm \tag{52}$$

Thus the right hand derivative of the true loss function evaluated at $x_i = x$ is given by the derivative of the above expression 52 added to the expression in 34. Differentiating 52, we get

$$\left(\frac{(x-\bar{m})^2}{2}-c\right)f(\bar{m})-\left(\frac{(1-\alpha)^2(x-\underline{m})^2}{2}-c\right)\frac{1}{1-\alpha}f(\underline{m})=0 \tag{53}$$

Thus the right hand derivative of the true loss function at a symmetric equilibrium is also given by 34.

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