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Julio J. Rotemberg

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ABSTRACT

A model is considered where firms internalize the regret costs that consumers experience when they
see an unexpected price change. Regret costs are assumed to be increasing in the size of price changes
and this can explain why the size of price increases is less sensitive to inflation than in models with
fixed costs of changing prices. The latter predict unrealistically large responses of price changes to
inflation for firms that do not frequently reduce their prices. Adjustment costs that depend on the size
of price changes also raise the variability on the size of price increases. Lastly, it is argued that the
common practice of announcing price increases in advance is much easier to rationalize with regret
concerns by consumers than with more standard approaches to price rigidity.

Julio J. Rotemberg
Graduate School of Business
Harvard University, Morgan Hall
Soldiers Field
Boston, MA 02163
and NBER
jrotemberg@hbs.edu

Price changes can trigger consumer regret. If a good is storable and people notice an increase in its price, they are likely to regret not having purchased earlier, while they regret not having waited if they see a price decline. Even for non-storable goods, a price increase can trigger regret if individuals were savoring anticipatory utility before the purchase. These anticipations might make it difficult for consumers not to buy, so they experience regret at having indulged in these anticipations earlier. The purpose of this paper is to study how firms should change their prices if they seek to act as if they empathized with these regret costs of their consumers.

While it does not directly absorb scarce physical resources, the regret experienced as a result of a price change is a cost, and the analysis is thus conducted as a comparison of regret costs with the fixed costs of price adjustment postulated in the influential papers of Sheshinski and Weiss (1977) and Golosov and Lucas (2007). There are two ways in which regret costs can be expected to differ from simple fixed costs. The first is that these costs ought to depend on the size of price changes, with regret presumably being larger when prices are changed by larger amounts. The second is that these costs can be reduced if people are told about future price changes in advance.

These two simple and intuitive properties of regret have several implications for the pricing by firms that act as if they empathized with their consumers' sentiments. The dependence of regret costs on the size of price adjustment makes firms less willing to institute large price changes. This matters in two contexts. The first is the effect of inflation on the size of price changes. In the Sheshinki and Weiss (1977) model, an increase in inflation leads firms to post substantially larger price increases whenever they do decide to raise their price. In practice, however, several papers have shown that the actual size of price increases rises only modestly when inflation rises. The lack of dependence of price changes on inflation is visible already in the early work on magazine prices by Checchetti (1986). It is brought to light even more clearly in Kashyap's (1995) study of catalog prices, in Goette, Minsch and Tyran (2005) analysis of Swiss restaurant data and in the Mexican and Norwegian price index studies carried out by Gagnon (2007) and Wulfsberg (2008) respectively.

Gagnon (2007) argues that the lack of substantial changes in the size of price increases when inflation rises does not constitute evidence against fixed costs of changing prices. He shows, in particular, that a model with fixed costs of changing prices predicts a modest effect of inflation on the size of price increases as long as individual firm productivity is random, as in Golosov and Lucas (2007). A key condition for this result to be valid, however, is that all firms have the same price adjustment parameters so that the probability that any given firm will lower its price conditional on a price change is equal to the fraction of total price changes that is made up of price reductions. In practice, however, the frequency of price adjustment varies a great deal across firms and declines are much more common among firms that change their prices frequently. This bears on the effect of inflation on the size of price changes for two reasons. First, the size of price increases is more sensitive to inflation for firms that adjust their prices less frequently. Second, and this is a somewhat subtler point, the relationship between the the frequency of price adjustment and the response of the size of price increases to inflation is convex. This occurs, in part, because a one percent change in annual inflation has a negligible effect on the size of the price changes of firms that adjust their prices continuously. As a result of this convexity, inflation raises the size of the average price increase by more than it raises the price increases of firms whose prices are adjusted at the average frequency.

Relative to fixed costs, regret costs reduce the extent to which firms with infrequent price changes let the size of their price increases respond to inflation. The reason is that an increase in the delay between price adjustments requires a larger price increase (and hence more regret) when inflation is higher. As a result, rises in inflation lead altruistic firms to reduce these delays, and this dampens the size of their price increases. Interestingly, this effect can be so large that increases in inflation lead firms to reduce the size of their price increases. This result my be of empirical relevance because Wulfsberg (2008) shows that the size of many Norwegian price increases rose when inflation fell after the 1980's.

When firms see larger price changes as more costly, their prices have another desirable property. This is that, relative to a fixed costs of price adjustment model that induces the

same average price increases, there is more dispersion in these increases. This result may seem surprising since it might be felt that the desire to avoid regret leads all price changes to be consistently smaller. This is true for any given stochastic environment faced by firms. However, to be consistent both with the average magnitude of price increases and with the proportion of prices changes that are price reductions, one must make the environment faced by firms with regret costs more volatile. What happens, then, is that firms with regret costs institute only small price changes when inflation erodes their price for a given level of their real costs. On the other hand, they are forced to make larger price changes when they are hit by the large changes in real costs that are necessary to account for their average behavior.

A somewhat different advantage of interpreting the costs of price adjustment as customer costs of regret is that one can then explain why firms warn customers in advance of price changes. A preannouncement of this sort would seem to have the potential to ameliorate two regret costs. First, it would urge customers who would be upset at paying a higher price later to purchase immediately and thereby avoid some of the costs of the price increase. Second, it could reduce the number of people who are surprised when they see the higher price, and thereby reduce the number of people who obtained anticipatory utility on the basis of imagining that they would obtain the good for less.

Since this paper does not derive regret costs from first principles, it cannot address the question of how much regret costs fall when firms announce their price changes in advance. What the paper does show is that altruistic firms do sometimes (though not always) benefit from preannouncements if these reduce regret costs. At the same time, the paper emphasizes that preannouncements of price increases reduce firm profits in more traditional models of price rigidity. What happens in these models is that firms make more profits at the "new" prices than at the old, so they should not encourage their customers to stockpile goods at the old price.[1] Therefore, the existence of these preannouncements provides at least some

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[1]Encouraging customers to stockpile items in advance of price increases also seems inconsistent with models where firms keep their prices rigid because they lack sufficient information to change them (see, for example Mankiw and Reis (2002) and Woodford (2008)). Once the firm learns its price is no longer optimal, there seems to be little reason to help customers buy more at a non-profit maximizing price.

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evidence for the importance of psychic costs that are not incorporated in standard models of price rigidity.

This paper studies implications of a model whose assumptions are meant to be somewhat appealing from an intuitive point of view, and does not discuss the psychological evidence underlying the consumer attitudes that motivate the analysis. It also does not explain why firms internalize the regret that consumers potentially experience so that they set their prices treating this regret as a cost. Rotemberg (2008) provides a general discussion of the empirical evidence of regret in purchase situations. Heidhues and Koszegi (2008) provide an elegant model of disappointment where consumers are disappointed when the price is higher than their anticipation of what this price will be. One important difference between their work and what is discussed here is that they suppose that this disappointment is eliminated if consumers do not purchase, and this can lead sales to fall sharply when prices are raised. I suppose, by contrast, that regret (at either not having purchased before or at having formed excessively optimistic forecasts of future prices) persists whether the consumer purchases or not. As a result, the level of purchases is based on a standard consumer optimization problem.

A model of the transmission of customer emotions such as regret to firm actions is presented in Rotemberg (2004). While it motivates what is done here, the results in this paper can also be seen as being based on a "reduced form" that may be derived in other ways. In any event, the model of Rotemberg (2004) leads firms to follow consumer wishes for fear of being found to be insufficiently altruistic towards them. One empirical advantage of this interpretation is that consumers do sometimes lash out against firms, and firms do seem to take actions to avoid this.

The paper proceeds as follows. The next section considers deterministic models to show that the dependence of adjustment costs on the size of price adjustment can explain why inflation has modest effects on the size of price increases. Section 2 turns its attention to a model with stochastic technology inspired by Golosov and Lucas (2007). It contains two parts. The first discusses the extent to which such a model can explain the empirical link

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between inflation and the size of price increases. The second shows that the dependence of costs of adjustment on the size of price changes can, for a given degree of price rigidity, increase the variability of price increases. Section 3 studies price preannouncements and Section 4 offers some concluding remarks.

1 The size of price increases with deterministic inflation and technology

1.1 Continuous time

Most of the results presented in this paper are derived from numerical exercises carried out with discrete time models. Nonetheless, it is worth starting with a deterministic continuous time model that is close to Sheshinski and Weiss (1977) because this model is analytically more tractable and can therefore provide intuition for the numerical results that follow.

Let p_t be the nominal price charged by the firm at t and let p_{t-} be the limit of the price charged at time x when x approaches t from below. Consumers are assumed to incur the cost $\ell(p_t, p_{t-})$ whenever p_t is not equal to p_{t-}. Consistent with the discussion in the introduction, these costs are assumed to depend on the size of price changes, with price reductions being costly as well.

Purchases are assumed to be made continuously with no possibility of storage (this is relaxed below). Leaving aside the costs of regret, which are assumed not to affect purchase decisions, consumers obtains the following utility by purchasing a sequence of q_t units of a particular good and of z_t units of a numeraire good

$$\int_0^\infty e^{-rt}(\frac{\theta}{\theta - 1}q_t^{\frac{\theta - 1}{\theta}} + z_t)dt,$$

where θ is a parameter. The presence of the numeraire good makes it easier to isolate what occurs in a single market; a more complete model would treat all goods symmetrically instead. The price of the numeraire good, p_{zt} grows at the instantaneous rate μ while consumers have access to an asset with an instantaneous nominal rate of interest of i. Letting

A denote the consumers' assets and $\dot{A}$ their time derivative,

$$\dot{A} = iA - p_t q_t - p_{zt} z_t + I_t$$

where I_t represents non-asset income. It follows that, unless $i = r + \mu$ individuals will not consume z smoothly over time. If this condition is satisfied, by contrast, individuals are indifferent as to when they consume z. Individuals can then reach their maximum utility by setting z_t equal to $\bar{z} - p_t q_t / p_{zt}$ where $\bar{z}$ is the annuity value of lifetime wealth in terms of good z, which equals $r[A_0 + \int_0^\infty e^{-i\tau} I_\tau d\tau]/p_{z0}$. Leaving aside regret, total utility is then equal to

$$\int_0^\infty e^{-rt} \left(\frac{\theta}{\theta - 1} q_t^{\frac{\theta-1}{\theta}} - \frac{p_t q_t}{p_{zt}} + \bar{z} \right) dt. \tag{1}$$

Consumer optimization then implies that $q_t = (p_t/p_{zt})^{-\theta}$ so that θ is the elasticity of demand. With a mass N of consumers, total demand is given by $Q_t = N(p_t/p_{zt})^{-\theta}$. Given this level of purchases, (1) implies that each individual's instantaneous utility from consuming the non-numeraire good is given by

$$\frac{\theta}{\theta - 1} q_t^{\frac{\theta-1}{\theta}} - \frac{p_t q_t}{p_{zt}} = \frac{1}{\theta - 1} \left(\frac{p_t}{p_{zt}} \right)^{1-\theta}. \tag{2}$$

To ensure that firms do not change prices at every instant, the function ℓ is assumed to have a positive limit as p_t goes to p_{t-} from above, even though $\ell(x, x) = 0$. The existence of such fixed psychological costs allows one to interpret the rigidity of prices as due exclusively to consumer psychology. If fixed psychological costs are regarded as implausible, the model can be interpreted as one that has both administrative and psychological costs of price changes, with the former being fixed and the latter being variable. Because administrative costs of changing prices are unlikely to depend on the size of the price change, the aspects of the model that hinge on this variability seem most easily interpreted as being due to the psychological forces that I stress.

The instantaneous cost of producing the good is cp_{zt} so that this cost rises at the general rate of inflation μ. Instantaneous profits at t in terms of the numeraire good thus equal $N(p_t/p_{zt})^{-\theta}[(p_t/p_{zt}) - c]$. A firm that acts as if it had an altruism parameter of λ towards

its consumers maximizes the sum of the present value of its profits and λ times consumer welfare (which includes the regret costs from price changes). Its objective is thus

$$\int_0^\infty e^{-rt} W(p_t/p_{zt}) dt + N\lambda \sum_i e^{-r\hat{t}_i} \ell(p_{\hat{t}_i}, p_{\hat{t}_i-}) \tag{3}$$

$$\text{where} \quad W(y) \equiv N \left\{ \frac{\theta - 1 + \lambda}{\theta - 1} y^{1-\theta} - cy^{-\theta} \right\}, \tag{4}$$

and the $\hat{t}_i$ represent the dates where the firm changes its prices.

To ensure stationarity, let ℓ depend on $(p_t - p_{t-})/p_{t-}$. This implies that the time between price changes, τ, remains constant over time. Each time the firm sets a new price, it chooses the same real price $S = p_t/p_{zt}$ so that its price rises by $100(e^{\mu\tau} - 1)$ percent. The variables S and τ maximize

$$\frac{1}{1 - e^{-r\tau}} \int_0^\tau e^{-rt} W(Se^{-\mu t}) dt + \lambda e^{-r\tau} \ell(e^{\mu\tau} - 1).$$

The first order condition of this maximization problem with respect to S is

$$\int_0^\tau W'(Se^{-\mu t}) e^{-(r+\mu)t} dt = 0, \tag{5}$$

so that the present value of the benefit of raising the price slightly has to be equal to zero over the period in which price is kept constant. The first order condition for τ is

$$\frac{e^{-r\tau}}{1 - e^{-r\tau}} \left\{ W(Se^{-\mu\tau}) - \frac{r \int_0^\tau e^{-rt} W(Se^{-\mu t}) dt + r\ell\lambda}{1 - e^{-r\tau}} - \lambda\ell'\mu se^{\mu\tau} \right\} = 0. \tag{6}$$

Integrating $\int_0^\tau e^{-rt} W(Se^{-\mu t}) dt$ by parts and using (5), (6) implies that

$$r\lambda\ell - \lambda\mu se^{\mu\tau}(1 - e^{-r\tau})\ell' = W(S) - W(Se^{-\mu\tau}). \tag{7}$$

In the case where $\ell' = 0$, this equation is identical to the equation in Sheshinski and Weiss (1977). It then states that the difference between firm welfare at the reset price S and firm welfare at the terminal price $s = Se^{-\mu\tau}$ equals the interest rate times the cost of price adjustment (which is $\lambda\ell$ when $\ell' = 0$). The intuition for this is that the product of the interest rate and the cost of adjustment is the benefit of postponing the adjustment of

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prices by a small amount of time, and that, at an optimum, this ought to equal the cost of doing so.

Sheshinski and Weiss (1977) prove a quite general result, namely that increases in inflation raise the size of price adjustments $e^{\mu\tau}$. Intuition for this result can be readily obtained from Figure 1, which depicts both the objective function W as a function of price as well and the pattern of price adjustment. The reset price S is above the price p^* that maximizes W. After being set equal to S, the real price is allowed to decline with inflation until it reaches $Se^{-\mu\tau}$, with the vertical distance between the initial and final W's being equal to $r\lambda\ell$ when costs are purely fixed. Now suppose that inflation rises to μ' and imagine that the firm were to keep the size of the price increase the same (so that it now keeps its price constant for a period of length τ' with $\tau'\mu' = \tau\mu$). Higher inflation would reduce the time it takes for prices to reach p^* after the price is set to S. This matters because, after this point, W' is positive, and the fact that these points are reached faster implies that they receive a higher weight in (5), the present value of W' that must be zero at an optimal price. Since the limits of integration are unchanged if the interval between prices becomes τ', it follows that the firm now wants to start with a price higher than S. Given the required relation between profits at the starting and ending price, the firm must end with a lower price so that the size of price increases is higher.

In the case where adjustment costs are psychological and ℓ' is positive, an increase in inflation has the additional effect of lowering the left hand side of (7) for a given τ. The firm thus acts as if its costs of price adjustment were lower when inflation is higher. This induces more frequent adjustments and tends to reduce the size of price increases. The intuition for this effect is simple. When inflation is higher, postponing a price increase by a given amount of time raises regret costs ℓ by more (because a postponement by a given amount of time dt requires a larger increase in price). Thus, an altruistic firms has an incentive to raise the frequency of its price adjustments.

1.2 Discrete time

This effect of inflation can be quantitatively important. To demonstrate this, I turn to a version of the model where decisions are made once per time period and time periods have discrete length. The variables p_t, q_t, i and p_{zt} continue to represent, respectively, the price and individual consumption of the good under study, the one period interest rate and the price of the numeraire at t. Letting ρ be the rate at which consumers discount payoffs one period into the future, each consumer's lifetime utility at t is

$$\sum_{j=0}^{\infty} \rho^j \left(\frac{\theta}{\theta-1} q_{t+j}^{\frac{\theta-1}{\theta}} + z_{t+j} - \ell(p_{t+j}/p_{t+j-1}) \right),$$

while each consumer's assets at t, A_t equal

$$A_t = (1+i)A_{t-1} - p_t(\tilde{q}_t + \hat{q}_{t+1}) - p_{zt}z_t,$$

where $\tilde{q}_t$ are the purchases of the good at t for consumption at t and $\hat{q}_{t+1}$ are the purchases of the good at t for use at $t+1$. For the moment, I set $q_t = \tilde{q}_t$ and $\hat{q}_t = 0$ so that purchases for inventory are ignored. This is relaxed when I consider preannouncements below. To avoid a strict preference for zero consumption of z_t at certain points, it must be the case that

$$\rho(1+i) = (1+\mu), \tag{8}$$

where μ is the one period rate of growth of p_{zt}, and I assume this from now on. This condition ensures that consumers are indifferent as to when they consume good z. Consumer demand q_t is then equal to $(p/p_z)^{-\theta}$ once again and single-period utility from having access to this good at price p/p_{zt} equals $(p/p_z)^{1-\theta}/(\theta-1)$. With a constant real marginal cost of production c, a firm which behaves as if it cared λ times as much about consumer utility as about its own profits has the same one-period objective as before. I now write it as

$$N \frac{\theta+\lambda-1}{\theta-1} \left\{ W\left(\frac{p_t}{p_{zt}}\right) - L\left(\frac{p_t - p_{t-1}}{p_{t-1}}\right) \right\}, \tag{9}$$

where

$$W\left(\frac{p_t}{p_{zt}}\right) = \left(\frac{p_t}{p_{zt}}\right)^{1-\theta} - \frac{c(\theta-1)}{\theta+\lambda-1}\left(\frac{p_t}{p_{zt}}\right)^{-\theta} \qquad L \equiv \frac{\theta-1}{\theta+\lambda-1}\lambda\ell\left(\frac{p_t - p_{t-1}}{p_{t-1}}\right). \tag{10}$$

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I normalize N so that $N(\theta + \lambda - 1)/(\theta - 1)$ equals one. If the firm keeps its price constant for J periods starting in period 0, it incurs its next adjustment cost in period J. Supposing it raises its real price to S whenever it changes it, the present value of its welfare is

$$
\begin{aligned}
U &= \frac{\sum_{j=0}^{J-1} \rho^j W(S/(1+\mu)^j)}{1 - \rho^J} - \frac{\rho^J L}{1 - \rho^J} \\
&= \left\{ \sum_{j=0}^{J-1} \rho^j (1+\mu)^{(\theta-1)j} S^{1-\theta} - \frac{c(\theta-1)}{\theta+\lambda-1} \sum_{j=0}^{J-1} \rho^j (1+\mu)^{\theta j} S^{-\theta} - \rho^J L \right\} \Big/ \left(1 - \rho^J\right). (11)
\end{aligned}
$$

For any choice of J, the firm then sets S to maximize the sum of the first two terms, which gives

$$
S(J) = \frac{\theta c}{\theta + \lambda - 1} \frac{\sum_{j=0}^{J-1} \rho^j (1+\mu)^{\theta j}}{\sum_{j=0}^{J-1} \rho^j (1+\mu)^{(\theta-1)j}}.
$$

It is convenient at this point to normalize c by setting $\theta c/(\theta + \lambda - 1)$ equal to one. This has the advantage that the optimal price equals one in the absence of inflation, and that departures from one are a measure of the effect of inflation on S. Using this normalization and substituting $S(J)$ back into (11) implies that the firm's objective function is

$$
U = \frac{1}{\theta} \frac{\left[\sum_{j=0}^{J-1} \rho^j (1+\mu)^{\theta j}\right]^{1-\theta} \left[\sum_{j=0}^{J-1} \rho^j (1+\mu)^{(\theta-1)j}\right]^{\theta} - \rho^J L}{1 - \rho^J}. \tag{12}
$$

Using this equation, it is straightforward to find the numerical values of J that maximize this objective for given parameter values. I conduct several such experiments for different values of inflation and for different degrees of sensitivity of regret to the size of price increases. The normalizations ensure that, for given θ, λ affects the firm's price only through L so that its main role here is to determine the extent to which the firm perceives the regret cost of its customers. Notice also that in (9), L is in the same units as the one period revenues that the firm derives from one customer $(p_t/p_{zt})^{1-\theta}$. This facilitates the interpretation of this cost.

The two remaining parameters of the model are ρ and θ. In the simulations, these are set to the values used in Nakamura and Steinsson (2007) so that ρ equals .96 at annual rates and θ equals 4. In this section, a period is taken to be a day (so that firms can in principle change their prices daily). The results is that the ρ used in these simulations is $.96^{1/365}$,

and similarly single period inflation μ satisfies $(1 + \mu) = (1 + \pi)^{1/365}$ where π is the annual inflation rate.

Consistent with the idea that both price increases and decreases cause some distress, the firm's perceived cost of price adjustment, L is given by

$$L_t = L_0 I_t + \left| \left(\frac{p_t - p_{t-1}}{p_{t-1}} \right) \right| L_1 = \left(L_0 + \left| (1 + \mu)^J - 1 \right| L_1 \right) I_t, \tag{13}$$

where L_0 and L_1 are parameters and I_t is an indicator variable that takes the value of 1 if p_t differs from p_{t-1}. The assumption that this function is fully symmetric is made for simplicity.

Results from simulating this model are reported in Figures 2-4. Each figure contains four specifications for these costs, where these specifications differ both in L_0 and L_1. What the specifications in each figure have in common is the size of price changes at the baseline inflation rate of 2.4%. Thus, the L_0's in each figure can be thought of as having been chosen so that, for the L_1's being considered, each induces the same price changes when inflation is 2.4%. Since price changes are common at this baseline inflation rate, the figures allow one to understand the implications of different L's for the effect of inflation increases on price changes. The baseline price increases used as illustrations in the figures have, in turn, been chosen because they have been observed in empirical studies.

Figure 2 considers specifications where price increases equal 23.5% when inflation equals 2.4%. This specification is inspired by Cecchetti's (1986) study of magazine prices. His data show that, on average, price increases for his sample of magazines equalled 23.5% in the 1960's when inflation averaged 2.4%. Cecchetti (1986) reports that an average of 7 years elapsed between price adjustments and that the size of the adjustments he observed matched closely the aggregate inflation that took place since the last time these prices were adjusted. This suggests that, if there were any price declines at all, they must have been extremely rare. While this does not justify using a deterministic model to try to match his observations, it at least suggests a benefit of trying to explain them with models that, like those in this section, imply the absence of price declines.

The costs of adjustment that are necessary to rationalize these large price increases

are much larger than the costs that are contemplated in the other two figures. As Figure 2 indicates, one can explain the price rigidity of magazines with a fixed cost of price adjustment equal to 35.6 times (daily) revenue.[2] Since the price in question is the newstand price of magazines, and magazines also receive revenue from subscriptions and advertisements, this represents a much smaller fraction of total daily magazine revenue. Still, it represents a substantial fraction of the expenditure on newstand magazines. With a λ equal to one, consumers would have to suffer disappointment costs from price increases that are essentially the same as the monthly price of a magazine, and these psychological costs need to be larger still if λ is lower. One potential explanation for such large disappointment costs is that price increases may lead consumers to regret not having obtained a subscription or not having brought alternate reading material with them. While uncomfortably high, these costs may be more believable than the administrative costs of changing prices. As Cecchetti (1986) argues, these are likely to be low for magazines because their price is literally printed anew in each issue.

If one views these costs as fixed administrative costs, an additional problem emerges. This is that the size of prices increases did not rise substantially in the 1970's. The average inflation rate in this period was 7.1%. According to the figure, price increases should thus have risen to equal 35.9% if this model were valid with fixed costs of changing prices. Instead, Cecchetti (1986) shows that price increases rose only to 25.3%. The figure also displays the predicted changes in the size of price increases when costs of price adjustment depend on the size of the price increase. The bottom-most line in the figure displays the prediction of setting L_1 equal to the value of 1000, and this parameter actually leads predicted price increases to decline. The line with $L_1 = 800$ predicts a price increase of 25.4% when inflation is 7.1%, so a parameter in this range can explain the behavior of magazine price increases. Still the implied level of regret costs are very sensitive to the size of price adjustments. The particular functional form for regret costs in (13) implies that the elasticity of regret costs

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[2]This value does depend on the other parameters of the model. It is lower if the elasticity of demand θ is lower, for example.

with respect to $(1+\mu)^J$ is $L_1((1+\mu)^J/(L_0+L_1((1+\mu)^J-1))$. This expression equals about 4.6 for the line with $L_1 = 800$ when these costs are evaluated at the 2.4% inflation rate.

Figure 3 and 4 focuses on somewhat more flexible prices. The former studies environments where price increases equal 9.9% at the baseline inflation rate. This is the size of price increases found by Wulfsberg (2008) in Norwegian CPI data from 1990 to 2004 (when inflation in Norway equaled 2.4% on average). It is also close to the size of price increases reported in Golosov and Lucas (2007). Given that the model involves no price declines, a price increase of 9.9% still involves periods of rigid prices that last four years. Instead, Figure 4 considers parameters L_0 and L_1 that yield price changes once a year. Bils and Klenow (2004) as well as Nakamura and Steinsson (2008) report more frequent changes when looking at the full population of prices in the the US CPI, while Dhyne *et al.* (2006) report somewhat less frequent adjustment in European CPI data.[3] What is certain is that different sectors behave quite differently with respect to price adjustment so that many prices are changed more frequently than this while others are more rigid.

One obvious implication of looking at prices that are adjusted more frequently is that the fixed cost of adjustment that are needed to rationalize this rigidity is lower. A less obvious result is that a smaller slope L_1 is needed to rationalize declines in the size of price increases when inflation rises. This is a useful result because Wulfsberg (2008) shows that the size of typical price increases was about 2.3% lower in the period 1975-1989 when average inflation in Norway was equal to 8.4%. As shown in the figure, one can obtain declines of roughly this magnitude by letting L_1 be equal to about 550. It should be noted, however, that while this derivative of L with respect to $(1 + \mu)^J$ is lower than what was needed to rationalize Cecchetti's (1986) finding, the elasticity of these regret costs with respect to $(1 + \mu)^J$ evaluated at an inflation of 2.4% is around 10.9 in this case.

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[3]Other studies that have found prices to be rigid for around a year include Blinder *et al.* (1988) and Gopinath and Rigobon (2008).

2 Stochastic costs of production

As emphasized by Golosov and Lucas (2007) a model where positive inflation is the only force leading firms to change prices cannot explain the behavior of all prices. The reason is that one observes many price declines. So, at least some firms face cost declines rather than cost increases. Golosov and Lucas (2007) propose to model this as a mean reverting stochastic process for the technology of each individual firm, and this approach has been followed, among others, by Midrigan (2008), Gagnon (2007) and Nakamura and Steinsson (2008). In this section, I use a variant of this model to study two questions. The first concerns how the connection between inflation and the mean size of price increases is affected by the introduction of this random technology. The second is the effect of adjustment cost on other aspects of the distribution of price changes.

2.1 The connection between inflation and the size of price increases with fixed costs

Gagnon (2007) shows that a model that is quite close to that of Golosov and Lucas (2007) implies that the size of price increases rises only very slightly when inflation rises. Gagnon (2007) corroborates this prediction with Mexican data. Unlike the Norwegian data of Wulfsberg (2008), Gagnon's (2007) Mexican data does not show the size of price increases declining with inflation. Still, the effect of inflation is much more modest than is implied by the deterministic model considered in the previous section and Gagnon (2007) rightly points out that the capacity of explaining this fact is an impressive accomplishment for the model with random technology.

What this evidence shows is that the changes in the size of price increases are consistent with a model where all firms have the same stochastic technology and fixed costs of changing prices. One difficulty with this approach, however, is that it has been widely recognized that firms differ a great deal in the extent to which their prices are rigid. For firms whose prices are flexible, one does not need a model of price rigidity. One is then left with the question whether the evidence is consistent with a model where *the firms whose price is relatively*

rigid have fixed costs of changing prices (and stochastic technology). This section takes a modest step towards answering this question. It shows that, even with stochastic technology, firms that face substantial fixed costs of changing prices behave in a manner that is quite similar to the firms considered in the previous section: their prices always increase and never fall, and the size of their price increases is quite sensitive to inflation.

Following Golosov and Lucas (2007), marginal cost is now assumed to equal c/a_t where a_t is an index of technology that evolves according to

$$\log(a_t) = \delta \log(a_{t-1}) + \epsilon_t^a, \tag{14}$$

and ϵ_t^a is an i.i.d. normal random variable with standard deviation σ_a while δ is a coefficient smaller than 1. This implies that W, the one period payoff to the firm leaving outside adjustment costs, is now equal to

$$W\left(\frac{p_t}{p_{zt}}, a_t\right) = \left(\frac{p_t}{p_{zt}}\right)^{1-\theta} - \frac{\theta - 1}{\theta a_t}\left(\frac{p_t}{p_{zt}}\right)^{-\theta}, \tag{15}$$

where this payoff has been written so that it incorporates the normalizations $N = (\theta - 1)/(\theta + \lambda - 1)$ and $c = (\theta + \lambda - 1)/\theta$. The firm arrives at t with a pre-existing real price p_{t-1}/p_{zt} and its value function can be written as

$$V\left(\frac{p_{t-1}}{p_{zt}}, a_t\right) = \max_{p_t}\left[W\left(\frac{p_t}{p_{zt}}, a_t\right) - L_t + E_t\rho V\left(\frac{p_t}{p_{zt+1}}, a_{t+1}\right)\right]. \tag{16}$$

where the cost L_t is given by (13) so that it equals zero if p_t is set equal to p_{t-1}. This optimization is solved by value function iteration on a grid. To keep the optimization problem manageable, the length of the period is set equal to a month. Adjacent points on the (log) grid for real prices differ by .002, which is the baseline deterministic inflation rate of p_{zt} and corresponds to an annual inflation rate of 2.4%.[4]

Following Nakamura and Steinsson (2008), δ is set equal to .66. The parameters that still need to be calibrated are then σ_a, L_0 and L_1. To consider the case of fixed costs, I abstract from L_1 at first. I then set σ_a and L_0 so that the model reproduces two key statistics.

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[4]The programs to carry out this optimization were adapted from those used by Nakamura and Steinsson (2008).

These are the fraction of price changes that are increases, which is used in the Nakamura and Steinsson's (2008) calibration, and the average size of price increases, which is used in the calibration of Golosov and Lucas (2007). The average size of price increases is set at 9.9% once again[5] and the fraction of price changes that are increases is set to the value of .65 found by Nakamura and Steinsson (2008). The resulting values of σ_a and L_0 as well as some additional statistics from this baseline simulation are reported in the first column of Table 1. One additional dimension in which the simulation performs well is that prices are predicted to change in 8.2% of the observations, which is close to the value of 8.4% found by Nakamura and Steinsson (2008) in US CPI data.[6]

The second column reports the effects of keeping all the parameters at their baseline values and raising the annual inflation rate to 10%. Consistent with the findings of Gagnon (2007), the average size of price increases rises only modestly. Here it rises by about 1%. By contrast, there are more substantial increases in both the overall frequency of price changes and the fraction of these changes that is made up of price increases. This result may suggest that the implications of the deterministic model of section 1 are not relevant.

Column 3 shows, however, that this result hinges a great deal on the fact that every good is predicted to have both price increases and price declines. As suggested earlier, the Cecchetti (1986) magazine price data appears to include few if any price declines. Similarly, there appear to be effectively no declines in the restaurant data presented in Goette, Minsch and Tyran (2005). Like magazines, these prices are quite rigid with an elapsed time between price changes of around six quarters. In fact, the model with fixed costs of changing prices that I have been studying does predict that, for a given stochastic process for a_t, price declines should essentially disappear from sample paths if the cost of changing prices is sufficiently high.

This is demonstrated in columns 3 and 4 of Table 1, where I simulate a firm that is

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[5]Golosov and Lucas (2007) use 9.5%.

[6]This match is not entirely surprising since Nakamura and Steinsson (2008) use this overall frequency to calibrate their parameters and I use the δ from their study. The simulation statistics are obtained by constructing a stochastic sample path of 10 million observations.

subject to the same stochastic process for a as the firms in columns 1 and 2 but whose L_0 is set equal to .125. This is a value that is close to the minimum one that ensures that prices only rise whether yearly inflation equals 2.4 or 10%. Column 3 considers the case where this firm faces a 2.4% inflation rate. While it never lowers its prices, the size of its average price increases is essentially the same as that for firms in column 1, where the adjustment cost is much smaller. As adjustment costs increase, the firm becomes more reluctant to lower prices and this reduces its incentive to raise prices by more (because of the fear of being stuck with a price that is too high if a rises).

Column 4 then simulates the actions of firms with $L_0 = .125$ in an environment where p_{zt} grows at 10% per year. This change in inflation raises the size of price increases from 9.9% to 15.9% very much in line with the deterministic results.[7] Thus, Goette, Minsch and Tyran's (2005) evidence that Swiss restaurants (who rarely if ever cut prices) kept the size of their price changes constant when inflation changed also constitutes evidence against this stochastic version of a fixed cost of price adjustment model.[8]

What keeps price increases from rising with inflation when $L_1 = 0$ as in the specifications in columns 1 and 2 appears to be the fact that the firm has the option of eliminating its price reductions when inflation rises. This is shown more generally in Figure 5. This Figure depicts the connection between a firm's adjustment frequency, its fraction of price declines, and the responsiveness of its price increases to inflation. The Figure is constructed by keeping the demand and technology parameters the same and considering firms that differ only in their L_0. Higher values of L_0 lead to a lower frequency of price adjustment, and this frequency (at 2.4% annual inflation) is used as the x-axis for the plots. The bottom plot shows that firms with higher adjustment costs are less likely to cut their prices (again at 2.4% annual inflation.) Since inflation is positive, they prefer letting their real prices erode by doing nothing. The top plot, meanwhile shows that the change in the size of the price increase

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[7]In Figure 3 a change in inflation from 2.4 to 10% leads the size of price increases to go from 9.9% to 16.3%.

[8]The same is true for the evidence in Kashyap (1995). Declines constitute only 8 percent of his sample of price changes and yet he observes no difference between the size of price increases in the 1970's and the size of price increases in the 50's, 60's or 80's.

induced by going for a 2.4 to a 10% annual inflation rate. The plot shows that firms that cut their prices frequently have price increases that are nearly unaffected by inflation. For firms that raise their prices between 50 and 65% of the time that they institute a price change, the induced rise in the size of their price increases hovers between 0 and 1%.

By contrast, the proportion of price decreases becomes more important as it falls below around 35%, and firms with fewer price reductions let the size of their price increases be affected more by inflation. The effect of inflation is particularly dramatic for firms with very infrequent price adjustments. Given the convexity of this plot, it seems fair to conclude that the average across firms of the increase in the size of price increases should exceed the increase of a firm whose frequency of price adjustment is the average one. To determine the exact prediction of the model one would have to know how many firms fall in each category.

Unfortunately, we do not even know the behavior of firms whose prices are adjusted at the average frequency. In the simulations of the calibrated model, the typical firm is assumed to have the average frequency of price changes as well as the average fraction of price increases. It is worth emphasizing, however, that the overall fraction of price changes that are decreases (35%) is significantly influenced by firms whose prices are flexible, since their prices are more likely to be observed changing. So, it is possible that a very large fraction of firms mostly raise their prices but that they change their prices sufficiently rarely that they contribute a disproportionately small amount to the overall volume of changes. In this case, the model would predict very substantial increases in the average size of price when inflation rises.

2.2   Adjustment costs that rise with the size of the adjustment

This section reintroduces $L_1 > 0$, this time into the model with stochastic a. I start by considering the case where $L_1 = .5$. Because this is a monthly model, the corresponding values for a daily model like that of Section 1 would be around 15, which is still smaller than most values considered in that section. The first column of Table 2 uses the parameters L_0 and σ_a that fulfilled the two calibration criteria in the case where L_1 was set to zero. I start with these parameters because, by allowing for a simple comparison with the case where

$L_1 = 0$, they help provide intuition for the effect of L_1

The first column of Table 2 indicates that adding the cost $L_1 = .5$ while keeping all other parameters the same reduces the size of price increases while also reducing the overall frequency of price adjustment. This combination of effects may seem surprising, so Figure 6 provides some intuition.

This figure depicts slices of the policy functions that result from setting L_1 equal to either zero or .5. Both panels of this figure show the price that firms would charge as a function of the price they inherit when $\log(a)$ is equal to .09. Recall that that overall mean of $\log(a)$ is zero so these slices involves relatively favorable technology. Two differences are apparent from this Figure. The first is that the model with $L_1 = .5$ has two different reset prices rather than one. A firm with $L_1 > 0$ that is changing its price because it inherits a price that is too low does not (unlike the case where $L_1 = 0$) set the same price as a firm that finds itself with a price that is too high. The reason, of course, is that such a firm suffers when its price changes are large and is able to reduce these costs by making smaller adjustments.

The second difference is that the band of inaction is somewhat longer in the case where $L_1 = .5$. In particular, firms with this L_1 allow their price to climb higher before they lower it. Particularly when a is temporarily high so that it is likely to fall (leading to a higher desired price) small price reductions appear not to be that valuable. These firms thus institute them only when their current price is further out of line from their desired price.

The second of these features implies both that price decreases are less common (because firms wait longer to institute them) and that price increases are less common (because it is less likely that firms will use price increases to offset recent price reductions that were followed by declines in technology). Price increases are also made less common by the fact that price declines, when they occur, are smaller. On the other hand, the fact that price increases are smaller means that a price increase is likely to be followed sooner by the need to raise price again. This last effect, however, appears to be smaller than the other two since the actual frequency of price increases also declines somewhat when $L_1 = .5$.

The net effect of all this is that the simulations in the first column of Table 2 do not satisfy

the target criteria: the size of price increases is too small and the fraction of price increases is too large. Keeping σ_a the same, one can fit the size of price increases by raising L_0. This increase in the cost of changing prices leads firms to be even more unwilling to cut prices, however, so that the fraction of price declines diminishes further. As already indicated, this is not really drawback from an empirical point of view since sectors like magazines have both infrequent price declines and large price increases. Still, if one wants all firms to have the same parameters while keeping the fraction of price increases equal to 65%, one must increase the variability of technology. The set of parameters σ_a and L_0 that matches the two target moments is displayed in column 2 of Table 2 and σ_a is now considerably larger.

The need to increase σ_a as L_1 is increased so as to keep the fraction of price increases at 65% limits the possibility of conducting numerical exercises with large values of L_1. The reason is that increases in L_1 now require larger grids of prices, and the size of the resulting grids quickly creates numerical problems. The result is that, for the values of L_1 that I was able to study, the effect of inflation on the size of price increases remains modest. This is shown in column 3 of Table 2, which demonstrates that the size of price increases does not change significantly when inflation is raised to 10% per annum.

While the requirement that σ_a rise to ensure that prices decline when $L_1 > 0$ limits the scope of the analysis, it does have an interesting and potentially important consequence. This is that the variability of the size of price changes is increased. This can be seen by comparing column 2 of Table 2 with column 1 of Table 1, both of which fit the target moments when inflation is 2.4%. The latter, however, exhibits a 15% larger standard deviation of price increases and nearly a doubling in the (admittedly small) proportion of prices increases that exceed 15%.

Among the 12 products considered in Kashyap (1988), a substantial fraction had price increases of less than 3% about 30% of the time while more than 10% of their increases exceeded 15%. As he notes, the dispersion of price increases observed in his data represented a challenge to models of fixed costs of changing prices.[9] If firms sometimes raise their prices

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[9]See also Carlton (1986).

by small amounts, and these small amounts represent the size of their bands of inaction, then they should keep their prices constant only when they are subject to minuscule changes in cost. This seems difficult to reconcile with the observation of large price changes, unless costs are quite variable. But, if costs are so variable, why are prices typically constant for such long periods of time. The fixed cost model thus seems inconsistent with long periods of price rigidity that are interrupted by price changes of extremely variable size. Some solutions have been offered, including that costs of adjustment vary randomly over time (Dotsey, King and Wolman (1999)), that firms use a stochastic device to learn when price adjustments might be appropriate (Woodford 2008), that customers' tolerance of price changes varies over time and firms know about this (Rotemberg (2005)), that some costs of changing prices are "free" (Midrigan (2008)), or that costs of production are subject to leptokurtic disturbances (Midrigan (2008) and also Gertler and Leahy (2006)). These channels may well be necessary to explain the observations even after the role of L_1 is taken into account. Still, it is interesting that costs of adjustment that depend on the size of the price adjustment can also contribute to the variability of price changes.[10]

This effect is particularly stark in the case of the illustrative parameters considered in column 4 of Table 2. By raising L_1 so that it equals 1.0 and simultaneously raising σ_a to the value of .19, one obtains significantly more volatile changes in the size of price increases. In particular, the fraction of price increases smaller than 3% is now 13% while that over 15% equals 19%. Prices are now considerably less rigid, since they adjust on average every 3 months. While helpful in raising the variability of prices, this example does not succeed in reproducing the findings of Kashyap (1988). In particular, Kashyap (1988) finds an even larger proportion of small changes and longer durations of constant prices. Moreover, the example in column 4 features many more price declines than are found by Kashyap (1988).

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[10]While this paper is concerned with price changes as opposed to with the response of output to nominal disturbances, it is worth noting that these issues are closely linked, particularly in models like Golosov and Lucas (2007). Midrigan (2008), in particular, shows a mechanism through which a higher variability of price changes is connected with a higher response of output to monetary shocks. The idea is that the timing of relatively large price changes is unaffected by monetary policy because these changes are due to idyosincratic cost shocks. Thus, the observation of relatively large price changes suggests that, as in Calvo (1983), the timing of many price changes is insensitive to monetary shocks.

The role of L_1 in this example can be clarified further by considering parameters that allow a model with $L_1 = 0$ to induce the same fraction of price increases under 3% and the same fraction of price increases above 15% as those in column 4. The values of L_0 and σ_a that induce this, as well as the results of simulating a model with them, are displayed in column 5 of Table 2. In some respects, these simulations turn out to be quite similar to those obtained in column 4. In particular, the average size of price increases is the same and the overall standard deviation of price changes is quite comparable.

The two simulations do differ in one crucial respect, however, and this is the advantage of considering a model with positive L_1: the simulation with $L_1 = 1$ has prices that change much less frequently. The reason for this is the (relative) reluctance of firms to lower prices when $L_1 > 0$. This cuts the frequency of price adjustment directly by reducing the number of price reductions. It also cuts indirectly the number of price increases because price reductions when $L_1 = 0$ require subsequent price increases when a suddenly falls.

3   Preannouncing price increases

A rather different challenge to the idea that fixed administrative costs of changing prices explain price rigidity is the prevalence of price preannouncements. In the case of non-storable goods, preannouncements do not affect the volume of transactions and are thus a matter of indifference to firms. Many goods are somewhat storable, however, and customers who are informed that the price of a storable good will increase ought to attempt to purchase in advance of this increase. Whether this is good or bad for firms depends on whether it is more profitable to sell at the low price prevailing just before an price increase or at the higher level prevailing thereafter.

In Benabou's (1989) model, selling at the high price is always more profitable because demand has an inverse L shape so the firm's reset price is also the profit maximum. In his model, consumers benefit by buying in advance of price increases and firms dampen this speculation by randomizing over the time at which they change their price. It follows that firms would certainly be harmed by announcing this timing in advance.

In the Sheshinski-Weiss (1977) model, equation (7) with $\ell' = 0$ implies that the firm has a higher payoff at the price after the price increase than before. The reason is simple: if increasing a price did not increase current profits, the firm would be better off postponing the cost of changing prices until this does raise profits. Indeed, (7) implies that the profit increase must be large enough to offset the benefits (in terms of the time value of money) of postponing the increase slightly. This profit increase implies that the firm strictly prefers selling at the new price to selling based on the same demand and the same cost at an earlier price. Given a discount rate that equals the interest rate, the firm is also worse off selling this quantity in advance.

The Sheshinski-Weiss (1977) model is most easily interpreted as one where the good is nonstorable. It can also be interpreted as one where the good is storable but consumers are totally inattentive so they focus only on their purchases for current use and act as if they had no idea what price will be charged next. Preannouncements can then be interpreted as ways of telling consumers that it is in their interest to store the item. According to this interpretation, preannouncements are bad for firms in the Sheshinski-Weiss model (1977).

To gain some perspective on the features of actual preannouncements, I searched for "price increases," "announced" and "effective" in a publication that regularly carries such notices, namely *Business Wire*. Confining myself to the period 10/02 to 10/04 and ignoring the stories that matched my search criteria but were actually concerned with other issues, I found 44 stories pertaining to companies who made announcements of price increases. Of these, 14 (32%) announced price increases over one month in advance, 25 (57%) announced them less than one month in advance but over 10 days in advance and only 5 announced that these would affect shipments that would take place in the next ten days.

Some of these preannouncements specify that the new prices will apply to shipments beyond a certain date, so it is not entirely clear whether customers can place additional orders and have these be shipped before the new price takes effect. Other stories are very specific on this point, however. When Maxell, a large supplier of devices that store information on magnetic media, announced on December 2, 2003 that the price of its main products would

rise by about 10% in February 2004, it explicitly said it was giving advanced warning so that Maxell customers would have "sufficient time to incorporate the pricing change into their future business planning." Similarly, the September 15, 2004 announcement by GrafTech that it was increasing electrode prices explicitly stated this price increase would only apply to *orders* received after October 1. More generally, announcements made with a large degree of advance notice such as Kimberly-Clark's announcement in March 2004 that it would increase its Kleenex prices by midsummer give customers the capacity to respond.[11]

I start by considering a simple variant of the model of Section 1 and show that, under plausible circumstances, firms that act altruistically would indeed avail themselves of the opportunity to preannounce price increases. This deterministic model also clarifies two reasons why a firm with fixed administrative costs of changing prices is loathe to preannounce. The first is the time value of money implies that consumer demand is reduced by buying earlier. The second is that optimal pricing ensures that the price after adjustment is more profitable than the one before. Nonetheless, there are conditions under which preannouncing is desirable for firms whose adjustment costs are thereby reduced. After discussing these conditions I turn to a model with random a, where the analysis is restricted to a calibrated model based on Golosov and Lucas (2007). In particular, the analysis of stochastic a supposes that costs of adjustment are fixed so that $L_1 = 0$.

Preannounced price increases are assumed to lead a fraction α of customers to consider stocking up on the good one period before the actual price increases. Given that consumers do not typically carry inventory and that future consumption is not substitutable for current consumption, preannounced price reductions would not have an effect in this model, and are thus ignored. Moreover, to simplify, I suppose that all customers act as if they are unaware of impending price increases unless these are preannounced, so that a fraction α of customers accumulates inventories in response to these announcements and the rest carry no inventory. This is obviously an extreme assumption but provides a simple way to capture that not all

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[11]While the intertemporal substitutability of the purchase of prepared coffee might be subject to question, it is interesting that Starbucks gave about 10 days notice before raising its prices in September 2004.

consumers respond to temporary price discounts.

As suggested in Section 1, I now let the consumption of aware consumers at t, q_t, be the sum $\hat{q}_t + \tilde{q}_t$ where $\tilde{q}_t$ is purchased at t while $\hat{q}_t$ is purchased at $t-1$ for t. Since there are no inventory holding costs, aware consumers buy at the time when it is cheaper to do so. Their access to a perfect borrowing market at rate i implies that buying at $t-1$ is cheaper if $p_{t-1}(1+i) < p_t$. If this condition is met, they buy all their time t consumption in advance and otherwise they buy it at t.

In the model of section 1, prices are either constant or they change by a factor $(1+\mu)^J$ where J is the period of price rigidity. Thus aware consumer only buy in advance in the period right before a price increase and do so only if $(1+\mu)^J > (1+\mu)/\rho$ where I have used (8) to substitute for $(1+i)$. This condition is fairly weak, however, so we would expect consumers to want to stock up in this context. If consumers do purchase in advance, their purchases for t, $\hat{q}_t$ maximize

$$\frac{\theta}{\theta-1}\hat{q}_t^{(\theta-1)/\theta} + \bar{z}_t - \frac{\hat{q}_t p_{t-1}(1+i)}{p_{zt}}.$$

Using (8), the condition linking the interest rate to inflation, this implies that aware consumers buy

$$\hat{q}_t = \left(\frac{p_{t-1}}{\rho p_{zt-1}}\right)^{-\theta},$$

and their welfare from buying the good is $(p_{t-1}/\rho p_{zt-1})^{1-\theta}/(\theta-1)$.

Ignoring costs of changing prices, a firm acting as if it were altruistic would behave as if its real payoff at $t-1$ from selling to these consumer were equal to

$$\frac{\theta-1+\lambda}{\theta-1}\left(\frac{p_{t-1}}{p_{zt-1}}\right)\left(\frac{p_{t-1}}{\rho p_{zt-1}}\right)^{-\theta} - c\left(\frac{p_{t-1}}{\rho p_{zt-1}}\right)^{\theta}.$$

Using the normalizations for N and c, the firm's gain at $t-1$ if it made all the sales for t at $t-1$ equals

$$\rho^{\theta}\left[\left(\frac{p_{t-1}}{p_{zt-1}}\right)^{1-\theta} - \frac{\theta-1}{\theta}\left(\frac{p_{t-1}}{p_{zt-1}}\right)^{-\theta}\right] = \rho^{\theta}W\left(\frac{p_{t-1}}{p_{zt-1}}\right), \tag{17}$$

where the equality is based on (10). If, instead, it sells all its goods for t at time t, the present value of its benefits as of $t - 1$ is $\rho W(p_t/p_{zt})$. Since $\rho^\theta < \rho$, the expression in (17) is lower when $W(p_t/p_{zt})$ is equal to $W(p_{t-1}/p_{zt-1})$. The reason is that, even if these W's were the same, the firm would sell less in period $t - 1$ because consumers have to pay the real interest rate to carry the goods forward in time. Moreover, in all the simulations I conducted with the model of section 1, the value of W in the period before price adjustment was below that in the period with the new price. Thus, if firms adjust their prices at t, $W(p_{t-1}/p_{zt-1})$ is less than $W(p_t/p_{zt})$. This is what one would expect given the analytic result in (7).

This establishes that preannouncements that lead to advance purchases are not attractive to firms that face administrative costs of changing prices (*i.e.* costs that are not reduced by the preannouncement itself). The next step is to study whether a firm would be willing to preannounce if it could thereby save some of its consumer's, and thus indirectly its own, regret costs. It seems reasonable to suppose that customers who are able to buy at the earlier price should not experience any regret (and may instead experience additional utility from having obtained better terms than less aware consumers). I thus focus on the case where the preannouncement eliminates a fraction α of the regret costs (which are incurred when the price changes at t, as before). In this case, preannouncing is worthwhile, so that no equilibrium without preannouncements exists, if

$$\rho(W(S) - L(\mu^J - 1)) < \rho^\theta W(S/(1 + \mu)^{J-1}) \tag{18}$$

For the cases analyzed in Figures 2-4, this conditions is always satisfied. The reason is that the adjustment costs L in these plots are depicted as fractions of revenue, which implies that they are large relative to W. A key reason these adjustment costs appear so large is that they are being compared to *daily* revenue. Because goods can only be inventoried for one period, what is being studied here is whether firms would be willing to announce their prices with enough advance warning to let people buy at the old price the goods that they would consumer the next day. The cost of this is low relative to the cost of adjustment.

It could also be argued that preannouncing price increases by one day would lead only

a small number of customers to buy in advance so that α is small and the benefits of this policy are small as well. Perhaps for this reason, preannouncements tend to involve somewhat longer periods. To incorporate this into the model, I run it again while treating each period as being a month long (*i.e.* by changing the period discount and inflation rates). For this analysis, L_1 is set equal to zero.

In this monthly model (18) continues to be satisfied for products whose price changes are equal to either 9.9 or 23.5%. On the other hand, the condition is violated for products that change price every year so that their price change equals 2.4% when inflation is 2.4%. The reason for these contrasting results is that L_0 is substantially smaller when prices are rigid for only one year. Once L_0 is small, the firm has less to gain by preannouncing its price increases.

When condition (18) is satisfied, there is no equilibrium without preannouncements. This means, however, that the equilibrium that does exist satisfies somewhat different equations. The reason is that, when setting its new price, the firms has to recognize both that only a fraction $1 - \alpha$ of its customers buy in the first period and that a fraction α of its customers buy in the last period for consumption one period hence. Thus, the firm's present discounted value of benefits from setting a price of S every J periods becomes

$$U = \frac{D_1 S^{1-\theta} - D_2 S^{-\theta} - \rho^J (1-\alpha) L}{1 - \rho^J} \tag{19}$$

where

$$
\begin{aligned}
D_1 &= \sum_{j=0}^{J-1} \rho^j (1+\mu)^{(\theta-1)j} - \alpha \left(1 - \rho^{(J-1+\theta)} (1+\mu)^{(\theta-1)(J-1)} \right) \\
D_2 &= \frac{\theta-1}{\theta} \left[\sum_{j=0}^{J-1} \rho^j (1+\mu)^{\theta j} - \alpha \left(1 - \rho^{(J-1+\theta)} (1+\mu)^{\theta(J-1)} \right) \right].
\end{aligned}
$$

The optimization of U yields a reset price S equal to $\theta D_2 / (1-\theta) D_1$ and this can be plugged back into (19) to obtain the optimal J. For small enough values of α, the resulting optimum is very close to the one obtained without preannouncements, so that (18) continues to hold and there are indeed preannouncements each time the price is changed.

I now let technology be random once again and let a_t follows the process in (14). Preannouncing price increases for $t+1$ at t now has the obvious disadvantage that the firm knows its marginal cost of production at t but does not know it for $t+1$. To see that this is indeed a disadvantage, imagine that the good is non-storable and that the cost of changing prices for $t+1$ is the same whether this is announced before or after the firm knows a_{t+1}. It is then obvious that the firm prefers to do it afterwards, where it still has the choice of charging the price it would have chosen at t and will typically prefer to deviate from this choice.

In spite of this disadvantage, consumer's ability to store the good at t for consumption at $t+1$ can make preannouncing price increases more attractive when a is random. This is true, in particular, when a firm expects its future costs to be higher than its current costs. By preannouncing a price increase this firm induces more customers to buy while its costs are relatively low, and this can be profitable. Notice that this preannouncement is only attractive if a firm finds itself simultaneously with low costs and a desire to raise prices, a combination which may not manifest itself very frequently. To obtain an estimate of this frequency, I study how often this occurs in simulated settings.

I focus, in particular, on firms whose environment is described by the model of section 2. For these firms, I consider two issues. The first is whether they would like to deviate from the equilibrium considered in Section 2 by announcing some future price increases in advance. The second is the extent to which they do announce prices in advance in an equilibrium model where this is possible.

I first consider a deviation that is temporary in the sense that a firm considers making one price preannouncement at $t-1$ but plans to return to the optimal policy computed in Section 2 thereafter. If the firm announces announces a price for t that exceeds $(1+i)p_{t-1}$, the firm increases its $t-1$ payoff by $\alpha\rho^\theta W\left(\frac{p_{t-1}}{p_{zt-1}}, a_{t-1}\right)$. In period, t, however, its one period payoff ignoring adjustment costs falls from $W\left(\frac{p_t}{p_{zt}}, a_t\right)$ to $(1-\alpha)W\left(\frac{p_t}{p_{zt}}, a_t\right)$. Then, in period $t+1$, the firm returns to the optimal policy and is free to make new price changes. This means that the present value of its benefits as of $t+1$ is $V(p_t/p_{zt+1}, a_{t+1})$, where this value

is given by (16). This deviating firm thus announces a price p_t that maximizes

$$\hat{V}_{t-1}\left(\frac{p_t}{p_{zt}}, a_{t-1}\right) = E_{t-1}\left\{(1-\alpha)W\left(\frac{p_t}{p_{zt}}, a_t\right) + \rho V\left(\frac{p_t}{p_{zt+1}}, a_{t+1}\right)\right\},$$

where E_{t-1} takes expectations based on information available at $t-1$. Equation (14) implies that a_{t-1} contains all available information at $t-1$ about both a_t and a_{t+1}, and this in turn implies that $\hat{V}$ depends on a_{t-1}. Moreover, the value of p_t/p_{zt} that maximizes this expression, which is denoted by $\hat{S}_t$ also depends exclusively on a_{t-1}. Thus, deviating by preannouncing a price is attractive relative to maintaining the plan implicit in (16) if

$$(1+\alpha\rho^\theta)W\left(\frac{p_{t-1}}{p_{zt-1}}, a_{t-1}\right) + \hat{V}_{t-1}(\hat{S}(a_{t-1}), a_{t-1}) - V\left(\frac{p_{t-1}}{p_{zt-1}}, a_{t-1}\right) > \rho\hat{L}_t. \qquad (20)$$

where the adjustment cost $\hat{L}$ for prices announced at $t-1$ for t is paid at t. An equilibrium without preannouncements exists only (20) is violated for all combinations of a_{t-1} and p_{t-1}/p_{zt-1} that are reached in equilibrium. Figure 7 shows the left and right hand side values of this inequality for several parameter values. Rather than depicting the left hand side for all possible values of the relative price p_{t-1}/p_{zt-1}, it does so only for those relative prices that make the left hand side as large as possible (for the given value of a). Not surprisingly, this value obtains for relative prices p_{t-1}/p_{zt-1} that are close to the values that lead firms to raise prices at $t-1$ if preannouncements are impossible.

Figure 7 draws the left hand side of (20) for the baseline parameters of Section 2 so that $L_0 = .0285$ and $\sigma_a = .0528$, and these are labeled as being the benefits of preannouncing prices. The figure displays the effects of three illustrative values of α, namely 0, .065 and .15. These benefits are upwards sloping in a because firms with low a face currently high costs so they gain relatively more by instituting their price increases immediately rather than postponing them, whereas the opposite is true for firms whose costs are temporarily low.

The figure also shows several possible values of $\hat{L}_0$. The simplest, of course, is L_0 itself. The line depicting this cost of adjustment is always above the benefit of preannouncement when $\alpha = 0$. This illustrates the result we have already discussed, namely that firms find it costly to precommit to future prices when this does not reduce their costs of price adjustment

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and when customers do not take advantage of such preannouncements. While the benefits of preannouncement remain below ρL_0 also when $\alpha = .065$, this is no longer true for high values of a when $\alpha = .15$.

This demonstrates the benefit of inducing consumers to stock up when a is temporarily high. It is worth noting, however, that there was no actual equilibrium outcome where firms would have gained from these preannouncements in repeated simulations of 10 million observations. The reason is that firms very seldom, if ever, find themselves with prices that are too low (so that they need to be raised) when a is high (so that costs are low).

Figure 7 also considers the case where preannouncements eliminate the regret costs of consumers who buy in advance, so that $\hat{L}$ is equal to $(1 - \alpha)L_0$. In this case, the maximum benefits of deviating by preannouncing exceed the costs of doing so for a larger range of a's. Indeed, one can find such a's even for $\alpha = .065$, when such a's do not exist if adjustment costs are independent of whether prices are announced in advance or not. Also, combinations of prices and a such that preannouncements are worthwhile are now observed in simulations when $\alpha = .15$. To understand how often firms would actually preannounce, one must construct an equilibrium where this is explicitly possible, and I do so now.

In such an equilibrium, p_{t-1} is no longer relevant at t if the firm has made a preannouncement at $t - 1$. I thus use the notation p_{t-} to denote the price that the firm has inherited at t, where this equals p_{t-1} if the firm is free to change its price at t while it equals $\hat{p}_t$, the price announced for t at $t - 1$ otherwise. The value function for the firm at t differs depending on whether it is free to change its price for t or not. Let $V^u(p_{t-1}/p_{zt-1}, a_t)$ denote the value in the former case while $V^c(\hat{p}_{t-}/p_{zt-1}, a_t)$ in the latter. If the firm does choose to preannounce its price for t at $t - 1$ and if the size of preannouncement costs $\hat{L}_t$ is independent of the size of the announced price change, it announces the price that maximizes $E_{t-1}V^c(\hat{p}_t/p_{zt}, a_t)$. It thus sets $\hat{p}_t/p_{zt}$ as a function of only a_{t-1}, which contains all the information the firm has at $t - 1$ about future a's. Let $\hat{S}(a_{t-1})$ denote this optimal real price. while $\hat{V}^c(a_{t-1})$ is the value of $E_{t-1}V^c(\hat{S}(a_{t-1}), a_t)$.

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At an optimum, V^u and V^c must satisfy

$$
V^u\left(\frac{p_{t-}}{p_{zt}}, a_t\right) = \max{}^*\left(\left\{(1+\alpha\rho^{-\theta})W\left(\frac{p_{t-}}{p_{zt}}, a_t\right) + \rho(\hat{V}^c(a_t) - \hat{L}_t)\right\},\right.
$$
$$
\left.\left\{\max_{p_t}\left(W\left(\frac{p_t}{p_{zt}}, a_t\right) + \rho E_t V^u\left(\frac{p_t}{p_{zt+1}}, a_{t+1}\right) - L_t\right)\right\}\right) \quad (21)
$$
$$
V^c\left(\frac{p_{t-}}{p_{zt}}, a_t\right) = \max{}^*\left(\left\{(1-\alpha+\alpha\rho^{-\theta})W\left(\frac{p_{t-}}{p_{zt}}, a_t\right) + \rho(\hat{V}^c(a_t) - \hat{L}_t)\right\},\right.
$$
$$
\left.\left\{(1-\alpha)W\left(\frac{p_{t-}}{p_{zt}}, a_t\right) + \rho E_t V^u\left(\frac{p_{t-}}{p_{zt+1}}, a_{t+1}\right)\right\}\right). \quad (22)
$$

In these equations, the max* operator gives the maximum of the two terms in braces except when p_{t-}/p_{zt} is greater $\hat{S}(a_t)/(1+i)$. When it is greater, this operator equals the second element in braces so that the gains from preannouncing accrue only when consumers find buying at p_{t-}/p_{zt} more attractive than waiting to buy at $\hat{S}$. These equations can be solved by value function iteration. This involves using the existing value of V^c and V^u at each iteration, first to compute $\hat{V}^c$, and then using (21) and (22) to compute the next round of V^c and V^u.

Once this procedure converges, one is left with two indicator functions $I^u(p_{t-1}/p_{zt}, a_t)$ and $I^c(p_{\hat{t}}/p_{zt}, a_t)$. The first takes the value of 1 when the maximum in (21) is the first expression so that a firm that has not preannounced at $t-1$ preannounces at t, and is otherwise zero. Similarly, the second takes the value of 1 when the maximum in (22) is the first expression so that a firm that has preannounced at $t-1$ preannounces at t once again. One is also left with the function $F(p_{t-1}/p_{zt}, a_t)$, which gives the real price p_t/p_{zt} that maximizes $W(p_t/p_{zt}, a_t) + \rho E_t V^u(p_t/p_{zt+1}, a_{t+1}) - L_t$. Given these functions, it is straightforward to simulate a sample path for p_t.

To carry out this simulation, one can use an indicator variable I_t^a which takes the value of 1 if a price is preannounced at $t-1$ and equals zero otherwise. The price p_t is then given by

$$
\frac{p_t}{p_{zt}} = I_t^a \hat{S}_t(a_{t-1}) + (1 - I_t^a)\left[I^u\left(\frac{p_{t-1}}{p_{zt}}, a_t\right)\frac{p_{t-1}}{p_{zt}} + \left(1 - I^u\left(\frac{p_{t-1}}{p_{zt}}, a_t\right)\right)F\left(\frac{p_{t-1}}{p_{zt}}, a_t\right)\right],
$$

while the indicator I_{t+1}^a is

$$I_{t+1}^a = I_t^a I^c(\hat{S}(a_{t-1}), a_t) + (1 - I_t^a)I^u\left(\frac{p_{t-1}}{p_{zt}}, a_t\right).$$

Using the same grid as in the case without preannouncements, the value and policy functions for this problem were computed and used to simulate long sample paths for p_t. One key statistic that is informative about these sample paths is the ratio of the number of times that I_t^a equals one (so that there is a preannouncement) to the number of times that prices increase from $t-1$ to t. This ratio is displayed for various parameter combinations in Table 3.

The first line shows that, consistent with the impression given by Figure 7, preannouncements do take place in equilibrium for the baseline parameters with $\alpha = .15$ when the costs of adjustment are reduced by preannouncing the price. For these same parameters, there are no observations with preannouncements when the costs of price adjustment are fixed. As α is increased to .2 in the second line, even firms with fixed costs of adjustment preannounce their price increases about one half of a percent of the time. Even then, the percent of the time that price increases are announced is larger (about 2% of the time) if the costs of adjustment is interpreted as a regret cost that is reduced by preannouncements.

The third line continues to let $\alpha = .2$ and considers the case where $L_0 = .125$, the value which eliminates price reductions in the analysis of Section 2. This higher L_0 reduces preannouncements both when adjustment costs are fixed and when they are variable. This result stands in contrast to the results for constant a discussed above, where increases in adjustment costs made preannouncements more likely when adjustment costs could be interpreted as being the result of regret.

One way of reconciling these apparently conflicting results is shown in lines 4 and 5 of Table 3. This considers the case with a lower standard deviation of σ_a, which brings the results closer to those of constant a. These lines show that, when $\sigma_a = .03$, an increase in L_0 from .0528 to .125 raise preannouncements considerably (from half a percent to 2% of price increases). The variability of a thus affects the dependence of preannouncements on the size

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of adjustment costs.

In the case where L_0 is relatively low, preannouncements become more common as a becomes more variable because firms are sometimes willing to raise prices when costs are low, and it is attractive to preannounce such price increases. We saw earlier that, in spite of a variable a, firms become unwilling to cut prices as costs of adjustment increase, and this also makes them reluctant to raise prices when costs are low (since such price increases would have a large chance of being followed by a desire to reduce prices). As costs of adjustment increase, such price increases become less common, and the corresponding preannouncements wane as well. Thus, the variability of a induces preannouncements with low L_o that become less common as L_o rises.

While this is not immediately apparent from line 3 in Table 3 the effects of increases in L_0 depend on the extent to which preannouncements reduce the size of adjustment costs. In the case of regret costs that are reduced by preannouncements, it remains easy to find parameters that lead firms to announce price increases in advance when $L_0 = .125$. All that is necessary is to increase α somewhat. Indeed, line 6 of Table 3 shows that such firms preannounce about one third of their price increases if α is set equal to .3. By contrast, α needs to be greater than or equal to .9 to induce any preannouncements by firms for whom L_0 is fixed, and the resulting fraction of price increases that are announced in advance is infinitesimal. It equals .0001 for $\alpha = .9$ and reaches .0003 for $\alpha = .999$ (so that the firm makes effectively no sales in the first month in which the preannounced price prevails).

4   Conclusions

When firm managers are asked why they keep their prices rigid, their predominant response is that consumers react antagonistically to price changes (Blinder *et al.* (1988), Fabiani *et al.* (2006)). At the same time, most of the formal literature deriving price rigidity from more basic frictions has emphasized administrative menu costs that have no direct connection with the psychological states of consumers. This paper suggests that this may be a mistake.

Administrative menu costs have three implications that seem problematic, at least for

firms whose prices are sufficiently rigid that they seldom lower them. These are that they imply that the size of price increases should rise substantially when inflation rises, that the volatility of price increases should be low and that firms would rarely if ever voluntarily encourage their customers to stock up products by announcing the date of a price increase in advance. By contrast, these three aspects of price adjustment seem easier to rationalize if one interprets costs of adjustment as being due to the regret experienced by consumers as they face price increases. Moreover, the notion that consumers suffer losses from price adjustment fits well with the idea that consumers complain when they observe price increases. These complaints are to be expected if, as in Rotemberg (2004), consumers regard it as unfair when firms fail to act somewhat altruistically towards them.

The model of consumer psychology considered here, and of the transmission of consumers' psychological costs to firms, is still fairly crude. This reflects in part the lack of a consensus on how to model social preferences and how to model emotions that are not directly related to the amounts that people consume. Still, the suggestion that psychological considerations of this sort may help explain empirical pricing practices will hopefully encourage further research on these issues.

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Table 1
Inflation and fixed costs of price adjustment

	1	2	3	4
Inflation rate (% annual)	2.4	10.0	2.4	10.0
L_0 (Fixed adjustment cost)	.0285	.0285	.125	.125
σ_a (S.D. of shocks)	.0528	.0528	.0528	.0528
Overall adjustment frequency (%)	8.2	10.7	2.0	5.0
Fraction of increases	.65	.85	1.0	1.0
Mean price increase (%)	9.9	11.0	9.9	15.9
S.D. of price increases	.027	.024	.016	.027
Fraction increases < 3%	0	0	0	0
Fraction increases >15%	.04	.06	.002	.60

Table 2
Variable costs of price adjustment: the effect of varying the parameters

	1	2	3	4	5
Inflation rate (% annual)	2.4	2.4	10.0	2.4	2.4
L_0 (Fixed adjustment cost)	.0285	.0390	.0390	.0017	$6.2e^{-6}$
L_1 (Slope of adjustment cost)	.5	.5	.5	1.0	0
σ_a (S.D. of shocks)	.0528	.097	.097	.19	.104
Overall adjustment frequency(%)	3.5	8.7	10.6	33.7	94.0
Fraction of increases	.988	.65	.85	.61	.49
Mean price increase (%)	5.8	9.9	10.6	9.5	9.5
S.D. of price increases	.013	.031	.032	.072	.070
Fraction of increases $< 3\%$	0	0	0	.13	.13
Fraction of increases $>15\%$	0	.07	.12	.19	.19

Table 3
Proportion of price increases that are preannnounced

	Parameters			Proportion	
	α	L_0	σ_a	with fixed cost	with regret cost
1	0.15	0.0285	0.0528	0	0.005
2	0.2	0.0285	0.0528	0.0037	0.02
3	0.2	0.125	0.0528	0	0.01
4	0.2	0.0285	0.03	0	0.005
5	0.2	0.125	0.03	0	0.83
6	0.3	0.125	0.0528	0	0.32
7	0.6	0.125	0.0528	0	0.91
8	0.9	0.125	0.0528	0.0001	*

Note: * denotes that convergence was not achieved in value function iteration

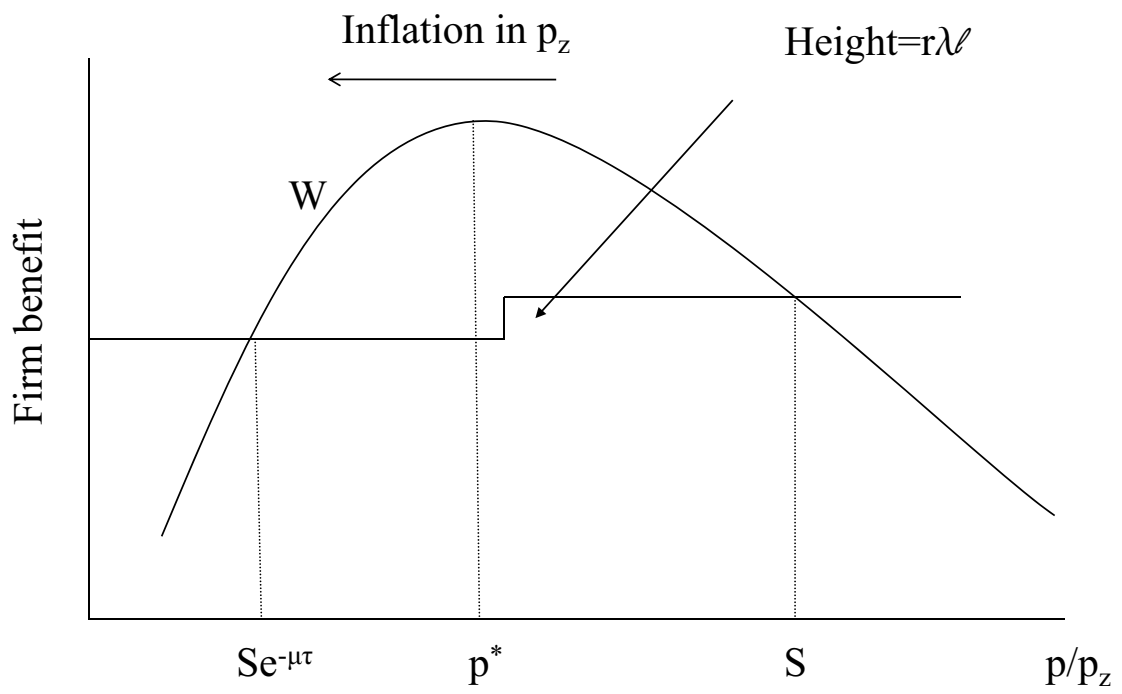Figure 1: Continuous time model of fixed adjustment cost

Figure 2: Size of price increases as one varies inflation and L_1. The case where prices are raised 23.5% under 2.4% inflation
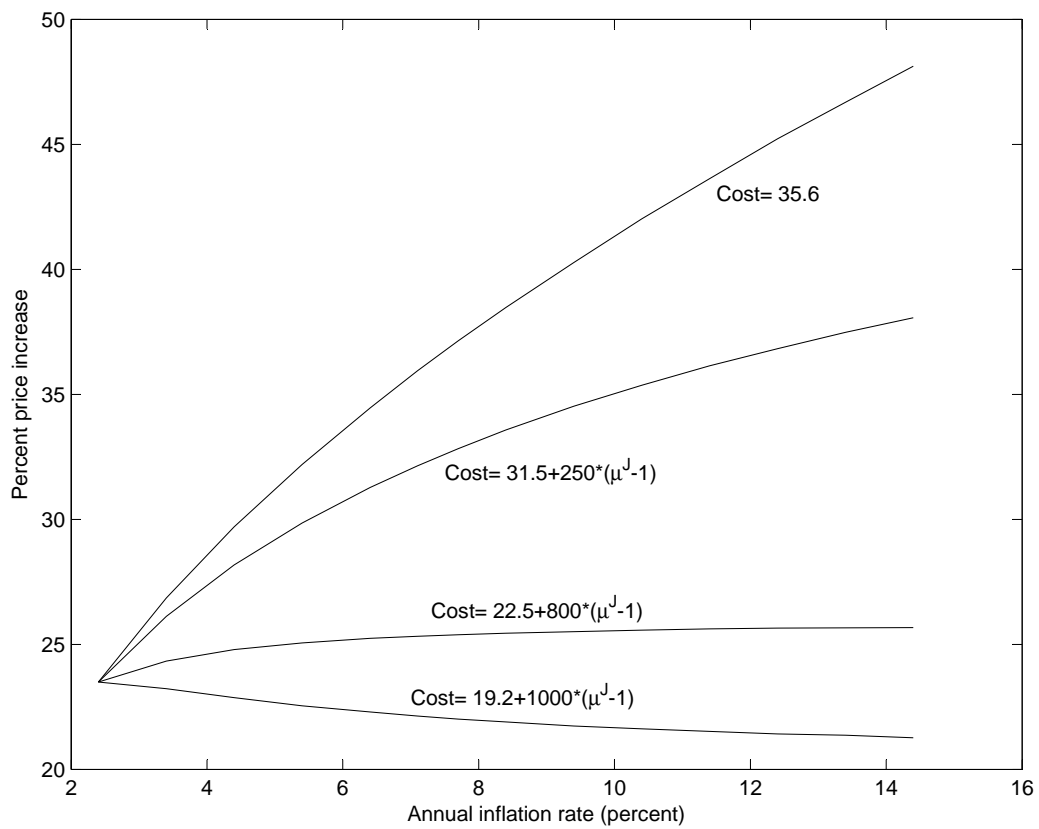
Figure 3: Size of price increases as one varies inflation and L_1. The case where prices are raised 9.9% under 2.4% inflation
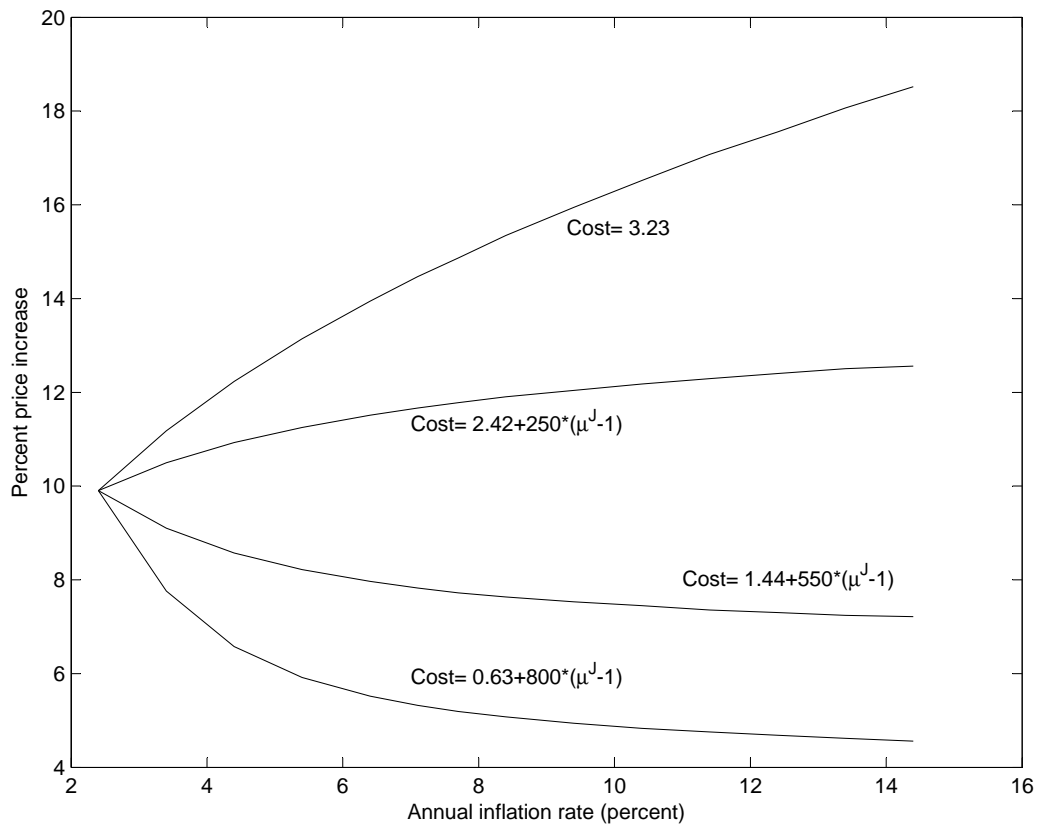
Figure 4: Size of price increases as one varies inflation and L_1. The case where prices are raised 2.4% under 2.4% inflation
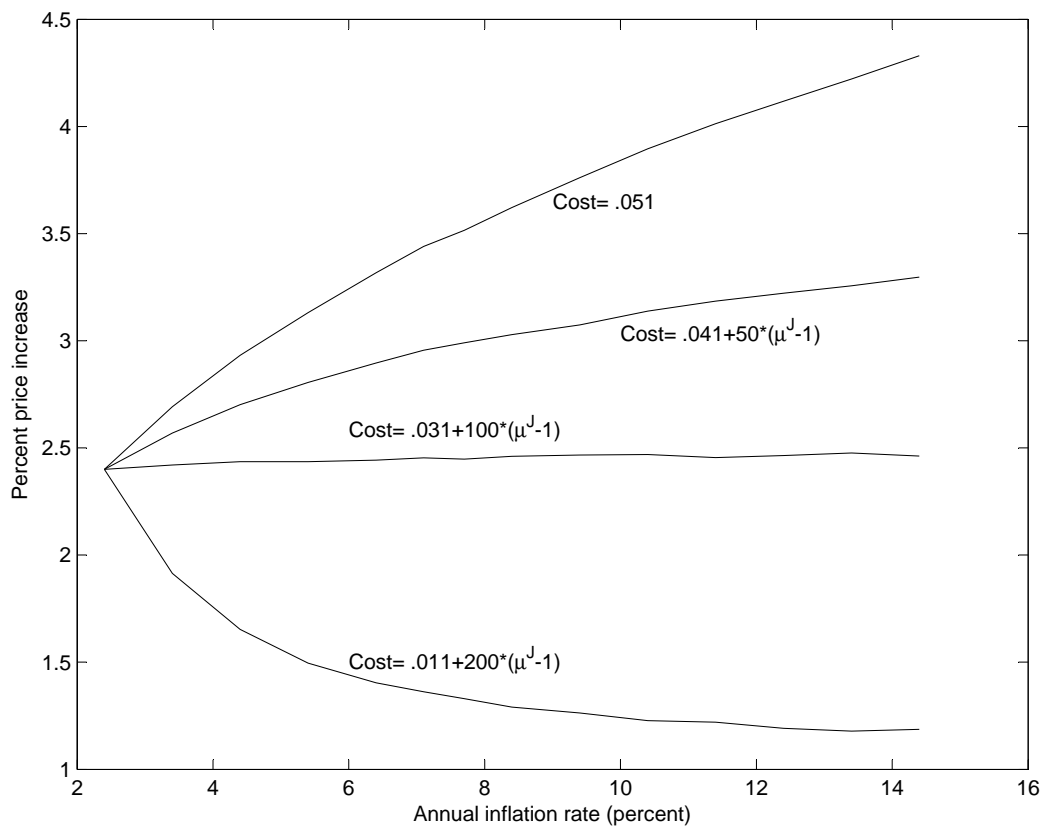

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Figure 5: The effect of raising inflation from 2.4 to 10% on the size of price increases for firms that differ in their frequency of adjustment at 2.4% inflation
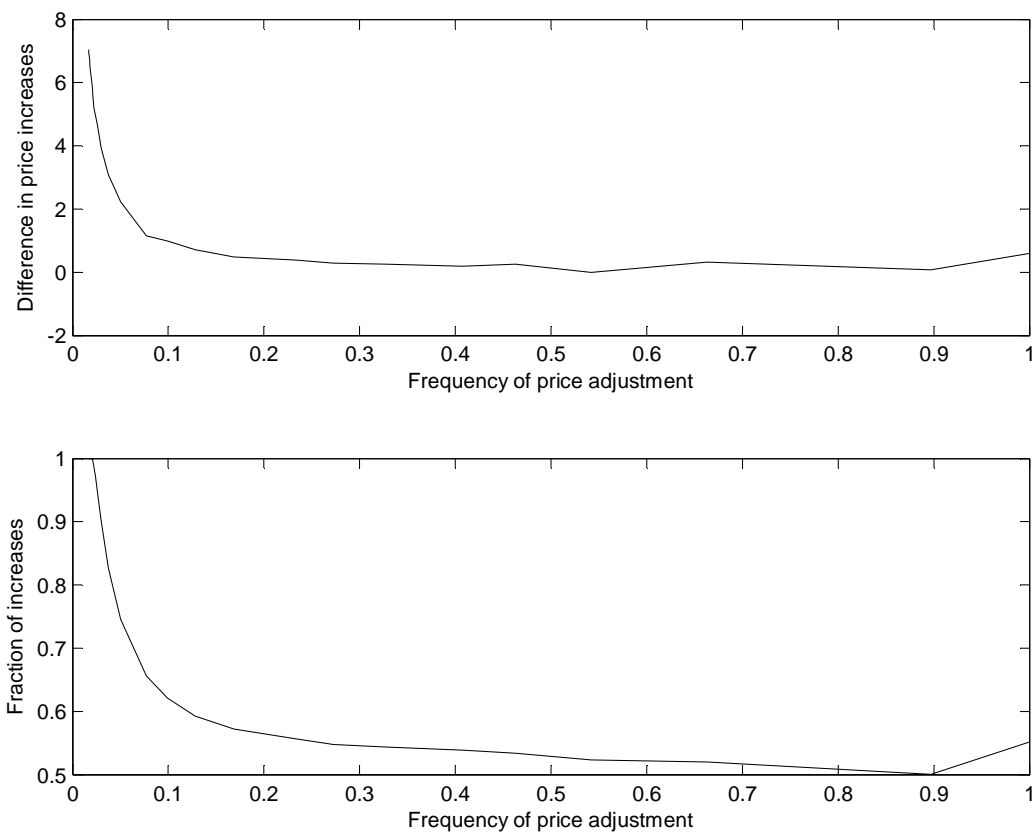
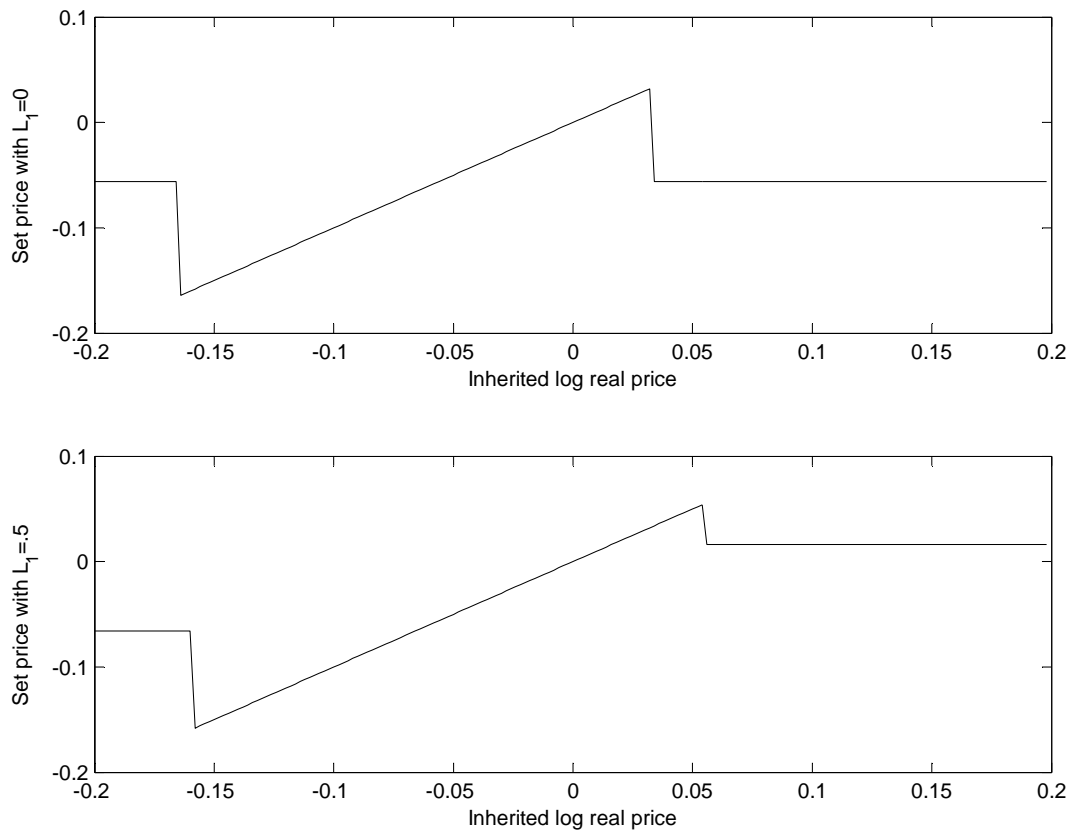Figure 6: Policy functions with $L_1 = 0$ and $L_1 = .5$

Figure 7: Benefits and costs of deviating by preannouncing price increases