Strategic Pricing Decisions in a State-Dependent Pricing Model

Doris S.Y. Poon*

The University of British Columbia

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Abstract

Empirical evidence shows that output and prices respond asymmetrically to positive versus negative and big versus small shocks in the economy. This paper uses a simple one-period, state-dependent pricing model to explain the asymmetric responses to monetary shocks. We find asymmetries in the effects of monetary shocks on output and prices, which can be explained by the strategic interactions in firms' pricing decisions. We also examine firms' pricing decisions when firms are allowed to follow mixed strategies. The magnitude of the shocks and the number of price-adjusting firms in the economy affect the mixed strategies that an individual firm follows. The model also shows that the degree of real rigidity in marginal cost, the costs of price adjustment and the firm's market power affect the asymmetric responses to monetary shocks, as well as the range of shocks that lead to mixed strategies in firms' pricing decisions.

*Email: dorissypoon@gmail.com

1 Introduction

A large literature in macroeconomics explains economic fluctuations using models with nominal rigidities. The models in the literature can be categorized into two main ways. The first category is the *time-dependent* pricing models, for instance Taylor (1980) and Calvo (1983), which assumes that firms leave their prices unadjusted for some fixed amount of time.[1] The number of price-adjusting firms is pre-determined exogenously, and each firm is constrained to adjust its price at pre-specified times. Firms are not allowed to respond to shocks between price-adjusting periods, and can only choose the prices to which they adjust, but not the timing of the price-adjustment.

As an alternative, the second category of models, the *state-dependent* pricing models, assumes that firms' pricing decisions depend on the state of the economy. Firms are assumed to face some small costs of price adjustment, and that they adjust only when the benefits outweigh the costs of price adjustment. State-dependent pricing is first introduced in microeconomic models, where a firm changes its price when price deviates from its optimal value (Barro, 1972). Caplin and Leahy (1991) set up a dynamic model with state-dependent pricing where money has systemic effects on output as firms follow a two-sided (S, s) rule, and find that the effects of monetary shock on output depend on the existing output level in the economy. Dotsey, King and Wolman (1999) incorporate state-dependent pricing into a dynamic general equilibrium environment by modifying Calvo's (1983) staggered contract framework, providing a tractable model of state-dependent pricing.[2]

Recent research has focused on the asymmetric effects of monetary shocks on output and prices. Empirical works provide mixed evidence on the asymmetries in the effects of monetary shocks. The seminal work by Cover (1992) studies the asymmetric effects of monetary policy on aggregate output in the US, and he finds that monetary contractions reduce output by a greater degree than does the amount of increase from equally-sized monetary expansions. De Long and Summers (1988), Karras (1996), and Florio (2005) also find evidence supporting the findings of Cover. On the other hand, Ravn and Sola (1996), Weise (1999), and Fischer, Sahay and Vegh (2002) find asymmetries in the effects of large versus small monetary shocks, but not in positive versus negative shocks.

Theoretical models that explain the asymmetric effects of monetary shocks are mainly built on the assumptions of costly price adjustment (menu cost models), positive trend infla-

[1]For a literature review on time-dependent pricing, see Taylor (1999), Goodfriend and King (1997) and Galí (2002).

[2]Other studies on state-dependent pricing include Caplin and Spulber (1987), Caplin and Leahy (1991, 1997), Ireland (1997), Burstein (2006) and Devereux and Siu (2007).

tion, and/or state-dependent pricing. Menu cost models suggest that firms face a small fixed cost for changing their prices, and firms adjust their prices only if the gains from adjusting prices exceed the costs of changing prices. Caballero and Engel (1992), Tsiddon (1993), and Ball and Mankiw (1994) use the sticky-price model with menu costs, and show that menu costs lead to asymmetric output and price responses to monetary shocks in the presence of positive trend inflation.[3] In the presence of a negative shock, firms have a smaller incentive to reduce their prices by paying the menu costs, as the positive trend inflation lowers firms' relative prices automatically between adjustments. However, a positive shock in the economy increases firms' desired relative prices while the trend inflation lowers them. Thus, firms are more willing to pay the costs to increase their prices. In contrast, Burstein (2006) and Devereux and Siu (2007) use state-dependent pricing models to study the business cycle asymmetries. Burstein (2006) finds that the economy responds asymmetrically to monetary expansions and contractions since firms are more averse to a lower than optimal relative price than to one that is too high in his model. On the other hand, Devereux and Siu (2007) find that the business cycle asymmetries are due to the strategic linkage among firms in their pricing decisions, and to the positive covariance of aggregate prices and marginal cost in the equilibrium.

The idea of strategic complementarity originally comes from the "coordination failure" literature, where an agent's optimal level of an economic activity depends positively on other agents' activity.[4] Ball and Romer (1991) link the "coordination failure" model with the "menu cost" approach to study firms' pricing decisions. They argue that nominal rigidity arises because of a failure in coordinating price adjustments among firms. They also find that firms' prices are strategic complements; that is, a greater flexibility of one firm's price increases the incentives for other firms to increase their price flexibility. In a recent research, John and Wolman (2008) use a state-dependent pricing model to extend Ball and Romer's analysis in a dynamic setting. The price complementarity in their model depends on the value of the discount factor, in particular, a low value of the discount factor leads to a high degree of complementarity. They also find that a region exists between flexible and sticky prices that contains no pure-strategy steady-state equilibrium, where firms randomize their choices of price flexibility.[5]

The model in this paper follows the work of Devereux and Siu (2007), with the focus on the strategic interactions among firms in their pricing decisions. Devereux and Siu

[3] Senda (2001) points out that the degree of asymmetry will lessen if the increase in the inflation rate is beyond some threshold level.

[4] For example, see Diamond (1982), Bryant (1983), and Cooper and John (1988).

[5] John and Wolman (2008) argue that the nonexistence of a pure-strategy equilibrium in that region is due to the discontinuity in the steady-state best-response correspondence of the firms, where an adjusting firm is indifferent between the adjusted price and the pre-set price strategies.

(2007) incorporate state-dependent pricing into a dynamic general equilibrium model to examine the business cycle asymmetries. Their model combines the characteristics of time- and state-dependent pricing, which makes the comparison of the responses of aggregate prices and output to monetary policy shocks under the two pricing schemes feasible. Instead of simulating and matching the model with the business cycle asymmetries in the US as in Devereux and Siu (2007), this paper focuses on the effects of strategic complementarity and that of substitutability in firms' pricing decisions. We use a one-period state-dependent pricing model with fixed cost of price adjustment to study the effects of monetary shocks on firms' pricing decisions and on the economy. We find the asymmetric responses of aggregate output and prices to positive and negative money shocks in this single-period model without positive trend inflation. Prices are downward sticky in face of negative money shocks and more flexible in response to positive shocks of the same magnitude. Firms' prices are *strategic complements* in the presence of positive monetary shocks: with a larger proportion of firms in the economy adjusting their prices, the greater is an individual firm's incentive to increase its price. For negative monetary shocks, firms' prices are *strategic substitutes*; that is, a firm has a smaller incentive to adjust its price when other firms adjust.

The main contribution of this one-period framework with a common fixed cost of price adjustment is to make the study of mixed strategies in firms' pricing decisions tractable, which add to the literature on state-dependent pricing models that has focused on the pure-strategy equilibrium. Our model shows the existence of a region between flexible and sticky prices where a firm adjusts its price with some endogenously determined probability. We find that firms only follow mixed strategies in face of some negative range of monetary shocks. A firm has a greater probability of lowering its price after negative monetary shocks when it expects that more firms in the economy are adjusting. In addition, the greater the magnitude of the negative shock, the higher is the probability that a firm lowers its price. Therefore, the probability of price adjustment depends on the magnitude of shocks and the behaviour of others firms in the economy.

We also find that the effects of strategic complementarity and substitutability depend on the elasticity of real wage with respect to output and the firm's market power. When the marginal cost is less sensitive to output fluctuations; that is, with a higher degree of "real rigidity," as defined by Ball and Romer (1990), the effect of strategic substitutability is dampened by the increase in strategic complementarity. When marginal cost is insensitive to negative output fluctuations (and the negative money shocks), an individual firm finds the gain in profit from lowering its price reduces. Therefore, it has less incentive to adjust its price unless many other firms are also adjusting. The effect of strategic substitutability also lessens when the firm's market power increases. Thus, when the market becomes more competitive, a firm has a larger incentive to lower its price in response to negative monetary shocks even if many other firms are also adjusting.

The rest of this paper is organized as follows. Section 2 sets up a one-period model. Section 3 examines the gains from adjusting prices and Section 4 studies the firm's pricing decisions. Section 5 concludes.

2 The model

Consider a one-period model of an economy with consumers and firms. Households consume differentiated goods and provide labour services to the final goods firms. They receive incomes from wages and from firms' profits. Firms are monopolistically competitive, and use labour hired in a competitive labour market for production.

2.1 Firm i

Assume there is a continuum of firms along the unit interval. Each firm i is a monopolist and produces a differentiated good using labour alone. The production function of firm i is:

$$Y_i = H_i \tag{2.1}$$

Since the labour market is competitive, the nominal marginal cost of production is given by the nominal wage, W.

Assume all firms must set their output prices before observing the state of the world. All firms in the economy choose the same price, $\bar{P}$, as all firms are ex-ante identical. However, a firm may choose to adjust its price ex-post by paying a fixed cost, κ. We can think of this cost as the physical ("menu") cost of price adjustment, or any cost incurred in changing prices. Assume that all firms face the same fixed price-adjusting cost.[6] Therefore, there are two types of firms in the economy ex-post; one with pre-set output price, and the other with adjusted price. Let s denotes the portion of firms in the economy that choose to adjust their prices ex-post.[7]

Prior to the realization of the state of the world, firm i's problem is to maximize expected profit by choosing its price, P_i, taking into account that it may choose to adjust its price ex-post with probability s:

$$\max_{P_i} \quad E_i \left\{ \Phi \left[(1-s) X_i (P_i - W) + s\tilde{\Pi} \right] \right\} \tag{2.2}$$

where

$$X_i = \left(\frac{P_i}{P} \right)^{-\lambda} X \tag{2.3}$$

X_i is the Dixit-Stiglitz demand faced by firm i and X is the aggregate market demand.[8]

[6] As our interest is in the strategic interactions in pricing decisions and the mixed strategies faced by a firm, for simplicity, we assume identical fixed cost for each firm in this one-period model. We cannot generate results with infrequent heterogeneous price changes with uniform fixed menu costs. For models with stochastic fixed cost of price adjustment, see Dotsey et al. (1999), and Devereux and Siu (2007).

[7] Since the firms lie on the unit interval, we can also view s as firm i's probability of price adjustment. We use s as the probability faced by a firm and the portion of adjusting firms interchangeably in this paper.

[8] Demand function, X_i, is obtained from the general equilibrium model below.

$\lambda > 1$ is the firm's own price elasticity of demand, Φ is the firm's state contingent discount factor,[9] P is the price level in the economy, and $\tilde{\Pi}$ is the gross profit that firm i can earn if it adjusts its price ex-post.

Solving this firm's profit-maximizing problem, firm i's ex-ante optimal price is:

$$\bar{P}_i = \hat{\lambda} \frac{E_i \left\{ \Phi P^{\lambda} X W \right\}}{E_i \left\{ \Phi P^{\lambda} X \right\}} \tag{2.4}$$

where $\hat{\lambda} = \frac{\lambda}{\lambda - 1}$ is the markup factor of the monopolistic firm.

After observing the state of the world, firm i can choose to reset its price to $\tilde{P}$ (by paying a fixed cost, κ), which equals to a fixed markup over the marginal cost:

$$\tilde{P}_i = \hat{\lambda} W \tag{2.5}$$

If the state of the world is known ex-ante, (2.4) and (2.5) give the same price, and there is no (gross) gain in profit by adjusting the output price ex-post.

Firm i's profit depends on its pricing decision. Let $\Xi = \{W, X, \bar{P}, s\}$. If the firm chooses to maintain its pre-set price after observing the state of the world, its profit is:

$$\bar{\Pi}(\Xi) = (\bar{P}_i - W) X_i = (\bar{P}_i - W) \left(\frac{\bar{P}_i}{P} \right)^{-\lambda} X \tag{2.6}$$

If the firm adjusts its price, then its profit becomes:

$$\tilde{\Pi}(\Xi) = (\tilde{P}_i - W) X_i = \frac{\hat{\lambda}^{-\lambda}}{\lambda - 1} W^{1-\lambda} P^{\lambda} X \tag{2.7}$$

The firm chooses to adjust its price to $\tilde{P}$ whenever the gross gain in profit exceeds the fixed cost of price adjustment. That is, firm i adjusts its price whenever:

$$\Delta(\Xi) \equiv \tilde{\Pi}(\Xi) - \bar{\Pi}(\Xi) \geq \kappa \tag{2.8}$$

where $\Delta(\Xi)$ represents the gross gain from price adjustment.

[9] The firm's state contingent discount factor, Φ, is determined from the households' preference, as households are the owners of the firm.

2.2 Households

A representative household maximizes its utility by choosing consumption of each good and labour supply subject to her budget constraint. Household's preference is given as:

$$\mathcal{U} = \frac{C^{1-\phi}}{1-\phi} - \eta H \tag{2.9}$$

where $\phi > 0$, and C is a composite consumption, which is characterized by a CES aggregator over the unit measure of differentiated goods:

$$C = \left[\int_0^1 C_i^{\frac{\lambda-1}{\lambda}} di\right]^{\frac{\lambda}{\lambda-1}} \tag{2.10}$$

Household receives wage income, profits of firms, and a lump-sum transfer from the monetary authority, and uses these incomes on consumption and money holdings. Thus, the household's budget constraint is characterized by:

$$PC + M = WH + \int_0^1 \Pi_i di + M_0 + T \tag{2.11}$$

where P is the price index described by equation (2.16), M is the household's choice of money holdings, M_0 is the initial money holdings, T is the total transfer from the monetary authority, and $\int_0^1 \Pi_i di$ is the total profits of the final goods firms, given to household in form of dividends. Assume that household must hold money in order to consume. Thus, household's money holdings must satisfy the cash-in-advance constraint[10]:

$$PC \leq M \tag{2.12}$$

Household's demand for good i is derived as:

$$C_i = \left(\frac{P_i}{P}\right)^{-\lambda} C \tag{2.13}$$

The household problem gives the labour supply condition:

$$W = \eta P C^{\phi} \tag{2.14}$$

[10]The CIA constraint binds in this one-period model. We introduce money to this state-dependent pricing model through the CIA constraint. Money-in-utility model can also serve the same purpose, but it complicates the algebra of this model while producing the same qualitative results.

Combining this with the cash-in-advance constraint, we have:

$$W = \eta P^{1-\phi} M^{\phi} \tag{2.15}$$

From the household's optimization, we get $\Phi = \frac{1}{PC^{\phi}}$; that is, the stochastic discount factor of the firm's profit maximization is equal to the marginal utility of household. We can use this since all firms are owned by households.

2.3 Equilibrium

Since a portion s of firms in the economy will choose to adjust ex-post, we can derive the aggregate price level in the symmetric equilibrium as:

$$P = \left[\int_0^s \tilde{P}_i^{1-\lambda} di + \int_{s+1}^1 \bar{P}_i^{1-\lambda} di \right]^{\frac{1}{1-\lambda}} = \left[(1-s)\bar{P}^{1-\lambda} + s\tilde{P}^{1-\lambda} \right]^{\frac{1}{1-\lambda}} \tag{2.16}$$

Define a symmetric, imperfectly competitive equilibrium, given any monetary policy rule, as the set of allocations, $\Theta = \{C, H, M\}$ and the set of prices, $\wp = \{\bar{P}, \tilde{P}, W\}$ such that:
(1) Firms maximize their expected profits by choosing optimal prices;
(2) Households maximize their utility over consumption and labour supply subject to budget constraints and CIA constraint;
(3) The money market clears:

$$M = M_0 + T \tag{2.17}$$

(4) Labour market clears:

$$H = Y \tag{2.18}$$

(5) The goods market clearing condition implies:

$$X = Y = C \tag{2.19}$$

In particular, the total output is:

$$Y = (1-s)\bar{Y} + s\tilde{Y} = X$$

where $\bar{Y}$ denotes the output of firms that do not adjust ex-post, while $\tilde{Y}$ represents the output of firms that adjust their prices ex-post:

$$\bar{Y} = \left(\frac{\bar{P}}{P}\right)^{-\lambda} C, \qquad \tilde{Y} = \left(\frac{\tilde{P}}{P}\right)^{-\lambda} C$$

3 Gains from price adjustment

In this section, we would like to look at the gains from ex-post price adjustment in order to understand the pricing decision of a firm when it observes the decisions of other firms. We look at two extreme cases: all firms adjust ex-post and none of the firms adjusts.

(1) When all other firms adjust, $s = 1$

When all other firms in the economy adjust their prices ex-post, from (2.16), the price level in the economy becomes: $P = \tilde{P} = \hat{\lambda}W$. There is only one type of firms in the economy, that is, the price-adjusting firms, so that the total profits received by the household is $\int \Pi = \tilde{\Pi}$.

Money demand becomes:

$$M = WH + \tilde{\Pi} = \hat{\lambda}WX \tag{3.1}$$

and wage is linear in money:

$$W = \varphi M \tag{3.2}$$

where $\varphi = \eta^{\frac{1}{\phi}} \lambda^{\frac{1-\phi}{\phi}}$.

Firm i's optimal pre-set price is:

$$\bar{P} = \hat{\lambda}\varphi \frac{E\left\{M^{\lambda}\right\}}{E\left\{M^{\lambda-1}\right\}} \tag{3.3}$$

Using (2.6), (2.7), (3.1) and (3.2), we can derive firm i's profits under the pre-set and adjusted prices as:

$$\bar{\Pi}(M|_{s=1}) = \hat{\lambda}^{\lambda-1}\varphi^{\lambda}\bar{P}^{-\lambda}M^{\lambda+1}\left(\frac{\bar{P}}{\varphi M} - 1\right) \tag{3.4}$$

$$\tilde{\Pi}(M|_{s=1}) = \frac{1}{\lambda - 1}\frac{M}{\hat{\lambda}} \tag{3.5}$$

Then firm i's gross gain from price adjustment, given that all other firms are adjusting ex-post, is:

$$\Delta(M|_{s=1}) \equiv \tilde{\Pi}(M|_{s=1}) - \bar{\Pi}(M|_{s=1}) = \frac{M}{\hat{\lambda}}\left[\frac{1}{\lambda-1} - \bar{P}^{-\lambda}\hat{\lambda}^{\lambda}\varphi^{\lambda}M^{\lambda}\left(\frac{\bar{P}}{\varphi M}-1\right)\right] \tag{3.6}$$

(2) When all other firms do not adjust, $s = 0$

When no firm in the economy chooses to adjust its price ex-post, the price level becomes $P = \bar{P}$, and $\bar{P}$ is given as:

$$\bar{P} = (\hat{\lambda}\eta)^{\frac{1}{\phi}}\left[\frac{E\{M\}}{E\{M^{1-\phi}\}}\right]^{\frac{1}{\phi}} \tag{3.7}$$

Money balances and wage become:

$$M = \bar{P}X \tag{3.8}$$

$$W = \eta X^{\phi-1}M \tag{3.9}$$

Firm i's profits under pre-set and adjusted prices are:

$$\bar{\Pi}(M|_{s=0}) = M\left(1-\eta\bar{P}^{-\phi}M^{\phi}\right) \tag{3.10}$$

$$\tilde{\Pi}(M|_{s=0}) = \frac{\hat{\lambda}^{-\lambda}}{\lambda-1}\eta^{1-\lambda}\bar{P}^{-\phi(1-\lambda)}M^{\phi(1-\lambda)+1} \tag{3.11}$$

and firm i's gross gain from price adjustment, given that no other firm chooses to deviate from the pre-set prices ex-post, is:

$$\Delta(M|_{s=0}) \equiv \tilde{\Pi}(M|_{s=0}) - \bar{\Pi}(M|_{s=0}) = M\left[\frac{\hat{\lambda}^{-\lambda}}{\lambda-1}\eta^{1-\lambda}\bar{P}^{-\phi(1-\lambda)}M^{\phi(1-\lambda)} - 1 + \eta\bar{P}^{-\phi}M^{\phi}\right] \tag{3.12}$$

Figure 1 plots the gross gains from price adjustment, equations (3.6) and (3.12), as functions of money shock. We use $\lambda = 11$, which is consistent to a 10 percent markup reported in Basu and Fernald (1997). We use $\phi = 1$ as the benchmark, where household's preference becomes logarithmic in consumption. The dashed line corresponds to firm i's gain from adjusting price when all other firms adjust their prices ex-post, while the solid line represents the case when all firms choose to maintain their pre-set prices. We can see that there are asymmetries in the gross gain functions. Since firm i's incentive to adjust ex-post depends on the gross gain and the fixed adjusting cost, Figure 1 also implies that firm i's pricing decision responds asymmetrically to exogenous monetary shocks. Note that the gains from price adjustment with $s \in (0,1)$ lie between the dashed and solid lines.

When $s = 1$, that is, when all other firms in the economy adjust their prices ex-post, there is a larger incentive for firm i to adjust its price in response to positive money shocks than to negative shocks . Firm i faces a higher nominal wage (that is, higher nominal marginal cost) after a positive money shock, as other firms increase their prices which lead to a higher price level after the shock. Firm i's demand increases if it remains to charge $\bar{P}$. If the positive shock is large enough, however, firm i's marginal profit falls or even becomes negative, and hence, leads to a lower profit even if its demand increases. Therefore, firm i has a large incentive to follow other firms to increase its price when there are positive money shocks. This is the *strategic complementarity* in firm i's pricing decision: the greater the share of other firms adjusting their prices in face of a money shock, the greater is the incentive of firm i to adjust its own price.[11]

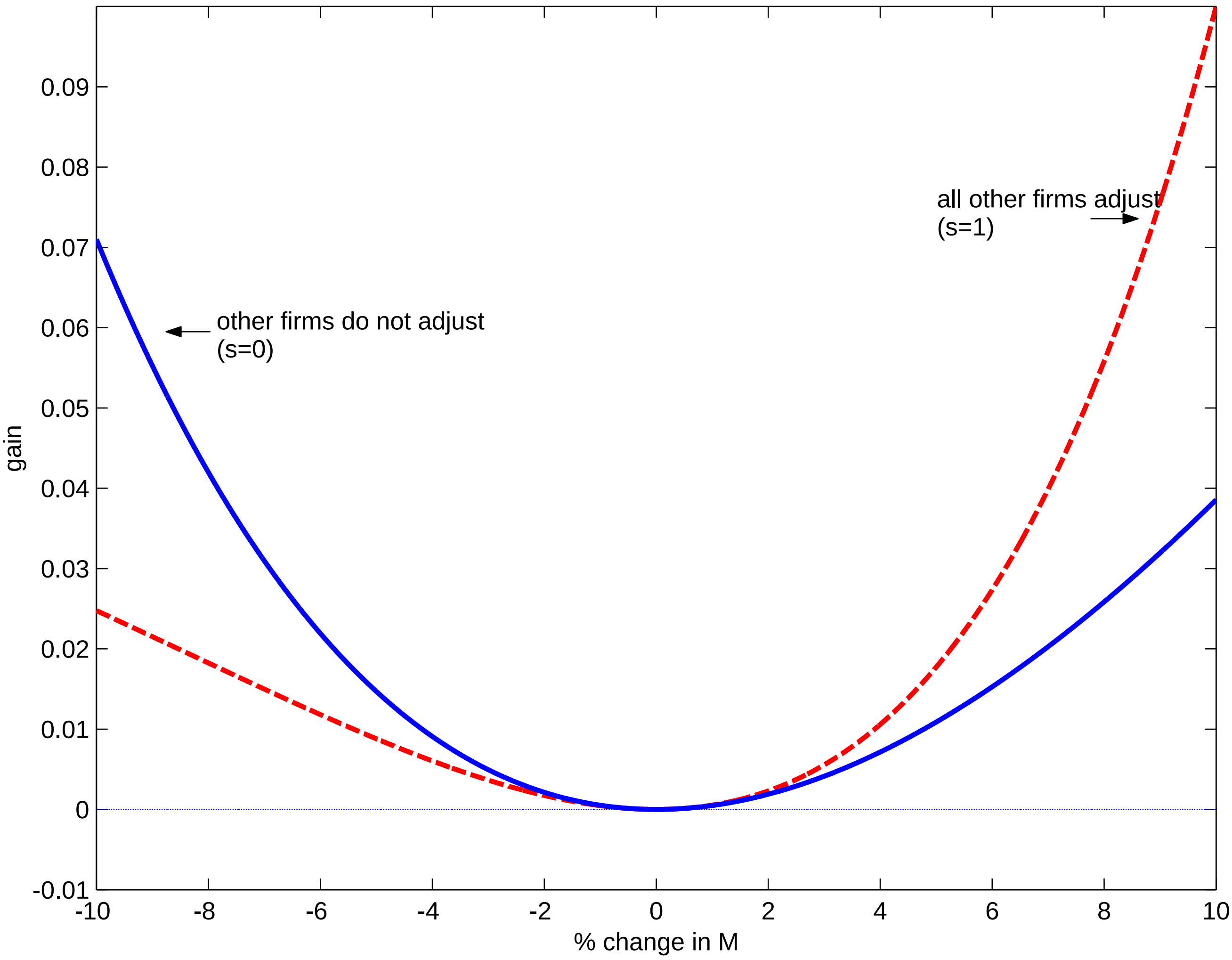
On the other hand, when there is a negative monetary shock in the economy, firm i has a smaller incentive to adjust its price when other firms adjust. When other firms lower their prices, the aggregate price level falls ex-post, which leads to a fall in firm i's demand and profit when it chooses to maintain $\bar{P}$. Firm i's profit, however, also drops even if it reduces its price ex-post, as the aggregate output in the economy and firm i's demand fall after a negative shock. The gross gain from lowering the price is smaller, therefore, firm i has a smaller incentive to adjust its price after a negative money shock when other firms in the economy choose to adjust. This is the *strategic substitutability* in firm i's pricing decision: the greater the share of other firms adjusting their prices in face of a money shock, the smaller is the incentive of firm i to adjust its own price.

When other firms maintain their prices ex-post (that is, $s = 0$), the asymmetry in firm i's pricing decision reverses. For positive money shocks, firm i has a smaller incentive to adjust when other firms do not adjust, while for negative money shocks, the firm has a larger incentive to adjust. When there is a negative money shock, firm i's demand increases if it lowers its price. Firm i's profit would fall by a smaller amount or even increase if the increase in demand is large enough. Therefore, firm i has an incentive to adjust when other firms do not adjust because the effect of strategic substitutability becomes larger. On the other hand, firm i is less willing to increase its price in face of positive money shocks, since its profit may fall due to a fall in demand.

[11] Burstein and Hellwig (2007) call this strategic interaction between firms' pricing decisions as *aggregate pricing complementarity*. In their model, they also focus on *firm-level pricing complementarity*, which arises from the change in firm's marginal cost through the changes in price level and firm's relative price. In our model, since we adopt a constant return to scale production function, the change in firm's marginal cost is solely due to the exogenous money shock. Individual firms interact only because of the change in aggregate price level.

Figure 1: Individual Firm's Gross Gains From Price Adjustment

$(\phi = 1)$



Now consider the case with $\phi < 1$, that is, the elasticity of real wage with respect to output is less than unity. Recall from equation (2.15), we have:

$$W = \eta P^{1-\phi} M^{\phi}$$

In the benchmark case, we use $\phi = 1$. The nominal wages move linearly with the money stock, or equivalently, real wages only respond to fluctuations in aggregate output (equation (2.14)). When ϕ approaches zero, nominal wages are less responsive to changes in money stock and output, and the changes in nominal wages are mainly induced by the changes in aggregate price level. Therefore, with $\phi < 1$, the presence of real rigidities further increases the interaction of firm i's price to other firms' prices, since the aggregate price level has a larger effect on firm i's marginal cost.

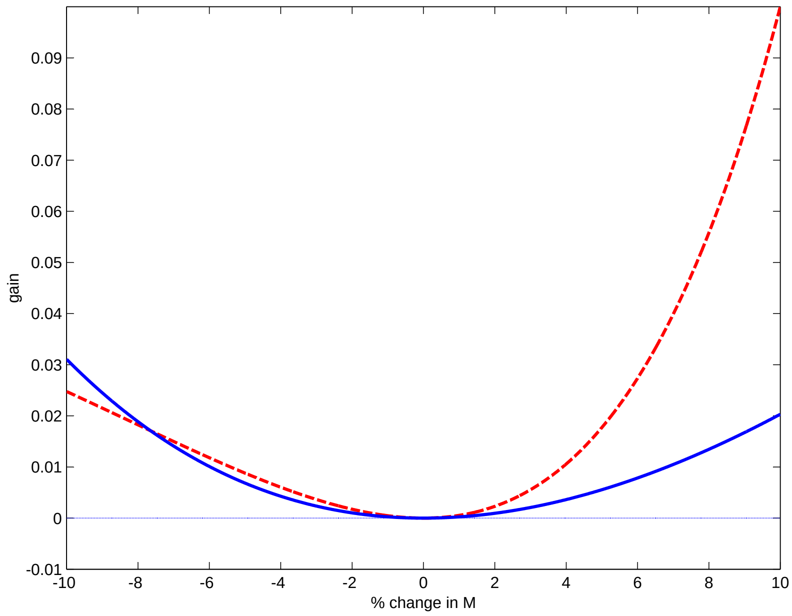
We plot firm i's gross gain functions with $\phi = 0.7$ and $\phi = 0.5$ in Figure 2. Panel (a) shows the gross gain functions when $\phi = 0.7$, and we find that there are two crossings of the gross gain functions. When comparing Figure 2 to the case with $\phi = 1$, the gross gain from price adjustment given $s = 0$ (the solid line) becomes flatter and less asymmetric within the $\pm 10\%$ money shock range, especially with respect to the range of negative money shocks. When $\phi < 1$, wages do not decrease one for one with the fall in money stock. If firm i lowers its price while other firms do not adjust, firm i's profit will be smaller than that under the case when $\phi = 1$. The increase in firm i's demand is now smaller, and hence, the gain from price adjustment is reduced. Therefore, firm i has less incentive to adjust. Firm i's pricing decision becomes more dependent on other firms' prices when there are real rigidities, and the effect of strategic substitutability in pricing decision decreases. When we further lower the value of ϕ (that is, increase the degree of real rigidities), panel (b) shows that the gross gain function given $s = 0$ becomes more flatter. The solid and dashed lines do not cross each other within the $\pm$ 10% money shock range, implying the effect of strategic substitutability is dominated by that of strategic complementarity in this range.[12] In general, with lower value of ϕ, that is, when wages are less responsive to changes in money stock (and hence, the aggregate output), the gain from price adjustment falls when other firms do not adjust, and the effect of strategic substitutability diminishes as ϕ approaches 0.

[12] The two lines do cross each other when the money shock is -15.78%. However, for low value of ϕ, the two functions are only tangent to each other at 0% money shock, and do not cross each other even for a $\pm$ 100% change in money stock.

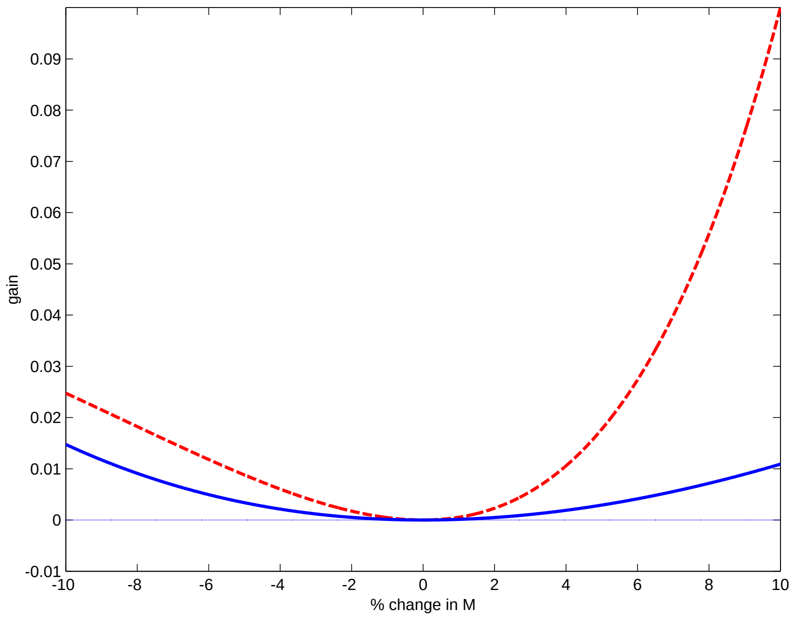
Figure 2: Effects of ϕ on Gross Gains From Price Adjustment

Dashed line: gain when $s = 1$; Solid line: gain when $s = 0$.

$(a) \quad \phi = 0.7$



$(b) \quad \phi = 0.5$



4 The pricing decision

From equation (2.8), we know that an individual firm's pricing decision depends on the gross gain from and the fixed cost of price adjustment. We use the gross gain functions to determine firm i's pricing decision. We arbitrarily assume the fixed cost of price adjustment, κ, equals to 0.02, and it is represented by a horizontal line in Figure 3 (which is a modified version of Figure 1 for illustration purpose). With $\phi = 1$, the $\kappa = 0.02$ line intersects the gross gain curves at four points, M_{ll}, M_l, M_h and M_{hh}, respectively. For any negative money shock larger than M_{ll} (in absolute term), firm i certainly chooses to lower its price ex-post, as the gross gain from price adjustment is larger than the fixed cost κ, regardless of the number of price-adjusting firms in the economy. For such a large negative shock, all firms find that it is profitable to lower their prices and expect other firms will also adjust. All firms adjust ex-post, and thus, $s = 1$ is sustainable. Similarly, for any positive shocks that are greater than M_h, firm i also pays the fixed cost and adjusts its price ex-post.[13]

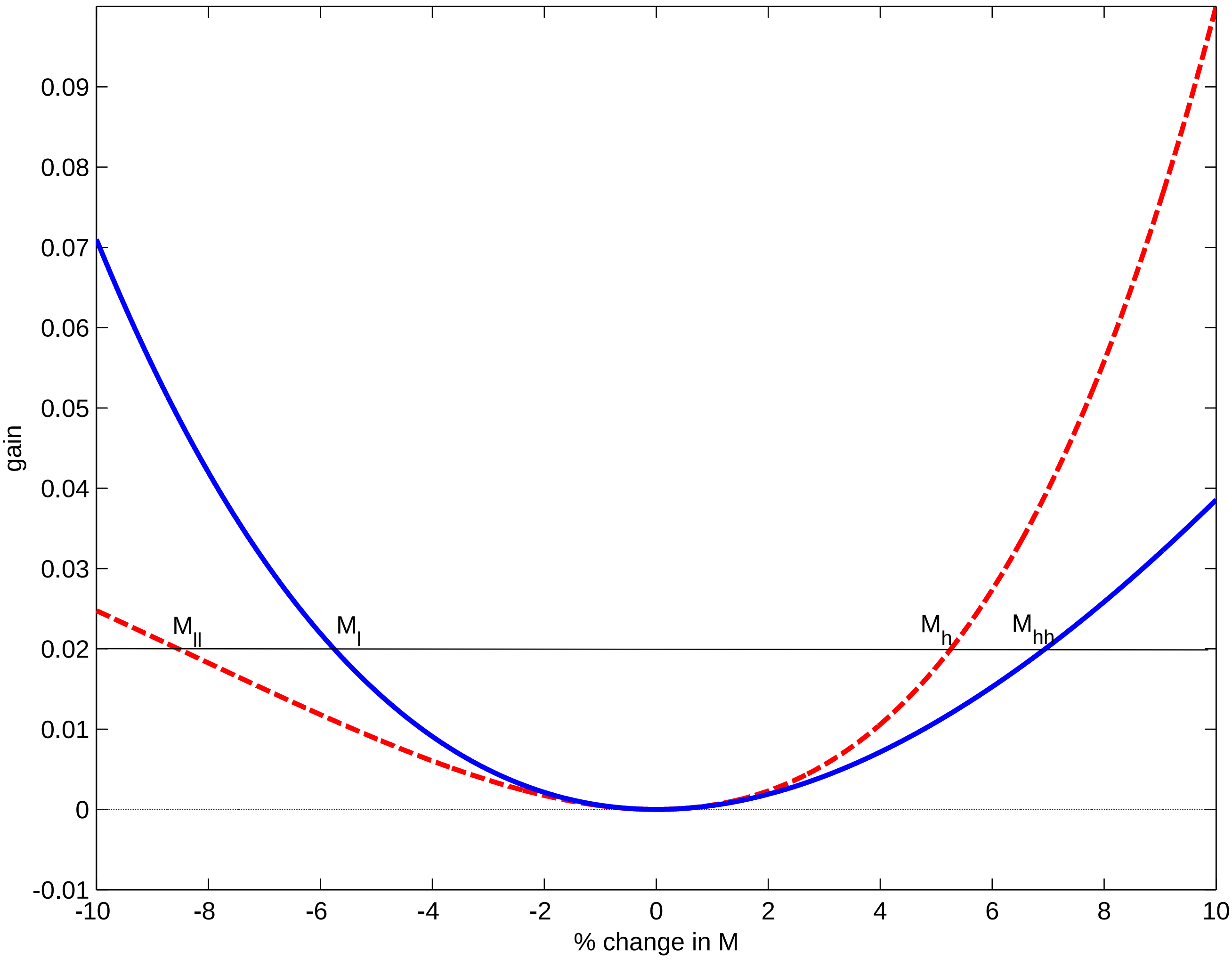
For relatively small negative and positive shocks that lie between M_l and M_h, firm i does not adjust its price ex-post, as the net gain from price adjustment is negative for all values of s. Firm i is better off without a price-adjustment. The region between M_{ll} and M_l is a region between the sticky-price and flexible-price pure strategies, where firm i randomizes its pricing decision. In this region, firm i is indifferent between the new flexible price and the pre-set sticky price in response to negative monetary shocks. Firm i uses mixed strategies in its pricing decision, in particular, it adjusts its price with probability $s \in (0, 1)$. The probability that firm i adjusts its price depends on the share of other adjusting firms in the economy. For negative shocks slightly greater than M_l, firm i adjusts only if s is close to 0. If firm i expects a lot of firms are adjusting, it will not adjust as the net gain is negative. Thus, firm i only has a small incentive to adjust when the shocks are relatively small in this range, and its incentive depends on the pricing decisions of other firms. While for larger negative shocks, firm i has a larger tendency to adjust (that is, when s is closer to 1) as net gain increases. Therefore, a typical firm i's pricing decision depends on the gross gain from and the fixed cost of price adjustment. Using the notations in Figure 3, we have:

Proposition 1. *Given $\Delta(M|_{s=1})$ intersects κ at M_{ll} and M_h, while $\Delta(M|_{s=0})$ intersects κ at M_l and M_{hh}, where $M_{ll} < M_l < \bar{M} < M_h < M_{hh}$. Then the probability that firm i adjusts its price in response to monetary shocks are:*

[13] For positive monetary shocks, the effect of strategic complementarity always dominates the effect of strategic substitutability. That is, the $\Delta(M|_{s=1})$ curve always lies above the $\Delta(M|_{s=0})$ curve. Therefore, as long as the net gain of price adjustment, given $s = 1$, is positive, firm i adjusts its price ex-post.

Figure 3: Individual Firm's Gross Gain and Pricing Decisions

($\phi = 1$)



$$
\begin{array}{llll}
\textit{I:} & \Delta(M,s) > \kappa & \Rightarrow \; s = 1 & \textit{for } M \geq M_h \\
\textit{II:} & \Delta(M,s) < \kappa & \Rightarrow \; s = 0 & \textit{for } M \in [M_l, M_h) \\
\textit{III:} & \Delta(M,s) = \kappa & \Rightarrow \; s \in (0,1) & \textit{for } M \in (M_{ll}, M_l) \\
\textit{IV:} & \Delta(M,s) > \kappa & \Rightarrow \; s = 1 & M \leq M_{ll}
\end{array}
$$

where $\bar{M}$ *denotes the steady-state money stock.*

Proof. See Appendix. □

When there are real rigidities (that is, $\phi < 1$), the range of negative shocks that leads to mixed strategies in firm i's pricing decision becomes smaller. For instance, we can see from panel (a) of Figure 2 that when $\phi = 0.7$ with $\kappa = 0.02$, the range of negative money shocks that leads to $s \in (0,1)$ is smaller (that is, the horizontal distance between the two functions is narrower). In addition, when we lower the fixed cost such that κ is below point C, firm i uses only pure strategies in its pricing decision: it adjusts whenever $\Delta(M|_{s=1})$ is greater than κ, and remains sticky when $\Delta(M|_{s=1})$ is less than κ. In panel (b) when the value of ϕ is low, since the $\Delta(M|_{s=0})$ curve is always flatter than the $\Delta(M|_{s=1})$ curve for any low value of κ, firm i's pricing decision only depends on the gross gain from price adjustment given $s = 1$. Thus, our model shows that lower the elasticity of real wage with respect to output, lower is the uncertainty in an individual firm's pricing decision, as the effect of strategic substitutability is dominated by that of strategic complementarity.

How can we determine firm i's probability of price adjustment when firm i faces a negative money shock that lies in Region III of proposition 1?

When firm i uses mixed strategies in its pricing decision (that is, $s \in (0,1)$), the money demand condition becomes:

$$M = WX + (1-s)\bar{\Pi} + s\tilde{\Pi} \tag{4.1}$$

where

$$\bar{\Pi} = (\bar{P} - W)\left(\frac{\bar{P}}{P}\right)^{-\lambda} X = \bar{P}^{1-\lambda}P^{\lambda-1}M - \eta\bar{P}^{-\lambda}P^{\lambda-\phi}M^{\phi+1} \tag{4.2}$$

$$\tilde{\Pi} = \frac{\hat{\lambda}^{-\lambda}}{\lambda-1}W^{1-\lambda}P^{\lambda}X = \frac{\hat{\lambda}^{-\lambda}}{\lambda-1}\eta^{1-\lambda}P^{-\phi(1-\lambda)}M^{\phi(1-\lambda)+1} \tag{4.3}$$

The price level in the economy is:

$$P = \left[(1-s)\bar{P}^{1-\lambda} + s\tilde{P}^{1-\lambda}\right]^{\frac{1}{1-\lambda}} \tag{4.4}$$

Firm i pre-sets its price at:

$$\bar{P} = \hat{\lambda}\frac{E\left\{\Phi P^{\lambda} X W\right\}}{E\left\{\Phi P^{\lambda} X\right\}} = \hat{\lambda}\eta\frac{E\left\{X^{1-\lambda} M^{\lambda}\right\}}{E\left\{X^{2-\phi-\lambda} M^{\lambda-1}\right\}} \tag{4.5}$$

and the wage equation can be written as:

$$W = \eta P^{1-\phi} M^{\phi} = \eta X^{\phi-1} M \tag{4.6}$$

From proposition 1, we know that firm i's gross gain from price adjustment must satisfy:

$$\Delta(M,\Xi) \equiv \tilde{\Pi}(M,\Xi) - \bar{\Pi}(M,\Xi) = \kappa \tag{4.7}$$

Substituting equation (4.6) and using the CIA constraint (2.12), equations (4.1), (4.5) and (4.7) can be used to solve for $\left\{X, \bar{P}, s\right\}$, for a given level of money stock, M.

Since we cannot solve this model analytically, we derive the probability of adjusting price numerically. Following the previous section, we continue to use $\lambda = 11$. Without loss of generality, we set the weight on labour supply in household's utility to one, that is $\eta = 1$. Again, we use $\phi = 1$ in the benchmark case, and use $\phi < 1$ for later experiments.

A key parameter to be characterized is the fixed cost of price adjustment, κ. As we have seen before, the value of κ plays an important role in firms' pricing decisions. In our benchmark calibration, we set the cost of adjusting price to 1 percent of the firm's steady-state revenue. We set this value by referring to some empirical studies on costs of price adjustment. For instance, Zbaracki et al.(2004) use the data of a large multi-product industrial manufacturer in the US to calculate the costs of adjusting prices. They categorize three types of price-adjusting costs, namely, managerial costs, customer costs and physical (menu) costs of changing prices, and the sum of these costs is about 1.23 percent of the firm's annual revenue. The managerial costs include costs in gathering information, making decisions, and communicating among departments within the firm, and these are estimated to be 0.28 percent of the revenue. 0.91 percent of the revenue are devoted as the customer costs, which are the costs of communicating and negotiating the price changes with customers. The physical costs, or menu costs of changing prices are about 0.04 percent of firm's annual revenue, and they are the actual costs of issuing the new prices.

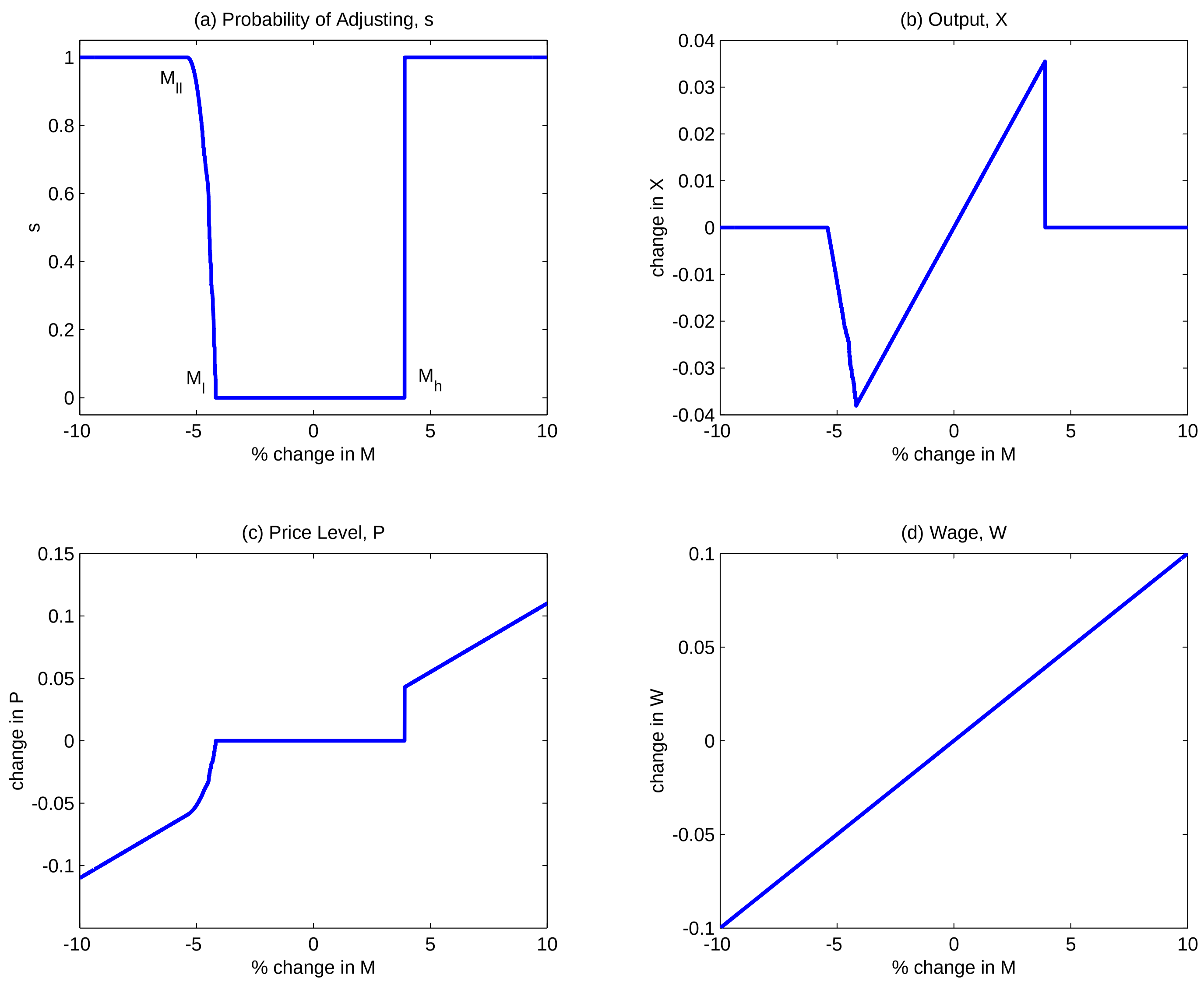
Levy et al. (1997) measure the actual menu costs at four multi-store retail supermarket chains in the US. They find that the average annual menu costs of a store is 0.7 percent of revenues. Although these findings are consistent with the common sense that the costs of price adjustment are generally very small when they are compared to the overall costs and revenues of a firm's activities, Levy et al. argue that the menu costs they find are large enough to form a barrier to price changes, and have macroeconomic significance, especially when they are applied to other industries or markets. We believe that our choice of κ is reasonable, as it lies between the values found by the above studies.[14]

(1) Benchmark case

Figure 4 shows the benchmark calibration with fixed cost of price adjustment equals 1 percent of firm's steady-state revenue. We plot the responses of aggregate output, price level and wage to exogenous money shocks that lie within the [-10%, +10%] range. Panel (a) shows the probability of adjusting price that an individual firm i faces. This also measures the proportion of firms in the economy that adjust ex-post. Positive money shocks greater than +3.90% (that is, point M_h in the graph) induce all firms in the economy to adjust, and prices become flexible. On the other hand, all firms choose to adjust only when the negative shock is more negative than -5.41% (point M_{ll}). This is the asymmetry discussed in Section 3: other firms' prices are strategic complements to firm i's price when there are positive money shocks in the economy, while their prices are strategic substitutes to firm i's price if shocks are negative.

[14] Slade (1998) uses weekly retail prices and sales of saltine crackers in a small US town to estimate the costs associated with price adjustments. She finds that the magnitude of fixed-adjustment costs is substantially higher than that of the variable-adjustment costs, approximately in the ratio of 15:1. Since we assume fixed cost of price adjustment in our model, if we apply this ratio to the total costs of price adjustment that are found in Zbarack et al. (2004), the fixed-adjustment costs account for about 1.1 percent of firm's annual revenue.

Figure 4: Responses to Monetary Shocks: Benchmark Model, $\phi = 1$, $\kappa = 1\%$ SS revenue



For negative shocks that lie between (-5.41%, -4.18%)(that is, between points M_{ll} and M_l), firm i's willingness to lower its price is increasing with the (absolute) magnitude of the shock and the share of adjusting firms in the economy. Larger the negative shock, greater is the loss of profits if an individual firm maintains its pre-set price due to the fall in aggregate output and firm's demand, and hence, greater is the number of firms deviate from their pre-set prices. Price level starts to fall when more firms reduce their prices, and it is more profitable for firm i to adjust. Therefore, firm i is more willing to lower its price to avoid further loss in profit.

Panel (b) of Figure 4 presents the output changes in response to exogenous money shocks. When no firm chooses to adjust its price, output increases when there is a positive money shock, and decreases when money stock falls. When all firms adjust ex-post and prices are flexible in the economy, money neutrality holds. When firm i follows mixed strategies in the range of (-5.41%, -4.18%), the magnitude of the fall in output becomes smaller when the shocks are getting more negative. More firms in the economy start to lower their prices when the shocks get more negative. Price level falls, which helps to lessen the fall in output. At the point where all firms have lowered their prices, money neutrality restores.[15]

Table 1(a) reports the distribution of output and price level under ±1%, ±5% and ±10% money shocks respectively. When the shocks are within ±1%, output and prices respond to shocks symmetrically. Firms do not adjust their prices so that price level is sticky in this range. For larger monetary shocks, firms' pricing decisions and the responses of the economy become asymmetric. When shocks lie between the [-5%, +5%] interval, the average increase in prices with respect to positive shocks is larger than the average price reduction in response to negative money shocks. Firms use mixed strategies in their pricing decisions in the range [-5%, -4.18%], in which the price level lies between the pre-set and adjusted prices. This lessens the average price deviation from the steady-state value, since for positive shocks, firms only follow pure strategies in their pricing decisions and prices jump from sticky to flexible prices. However, the average price adjustment deviates more from the steady-state value in response to negative shocks than that to positive shocks when shocks are in the ±10% range. Therefore, we find asymmetries in the responses of output and price level to positive versus negative shocks, as well as asymmetries in small versus big shocks.

[15] This is an "unrealistic" result of this one-period model. In practice, a large fall in money stock leads to fall in output.

Table 1: Distribution of Variables
($\lambda = 11$, $\kappa = 1\%$ of steady-state revenue)

(a) Benchmark ($\phi = 1$):

M shocks	-1%	$+1\%$	-5%	$+5\%$	-10%	$+10\%$
$E(X)$	0.9046	0.9136	0.8893	0.9229	0.8990	0.9160
σ_X	0.0026	0.0026	0.0106	0.0117	0.0123	0.0108
$E(P)$	1.1	1.1	1.0946	1.1107	1.0561	1.1466
σ_P	8.66×10^{-15}	8.66×10^{-15}	0.0134	0.0203	0.0413	0.0403

(b) $\phi = 0.7$:

M shocks	-1%	$+1\%$	-5%	$+5\%$	-10%	$+10\%$
$E(X)$	0.8683	0.8771	0.8509	0.8860	0.8600	0.8794
σ_X	0.0025	0.0025	0.01265	0.0112	0.0154	0.0103
$E(P)$	1.1459	1.1459	1.1459	1.1571	1.1053	1.1944
σ_P	4.44×10^{-16}	4.44×10^{-16}	5.00×10^{-14}	0.0212	0.04522	0.0419

(2) With some degree of real rigidity

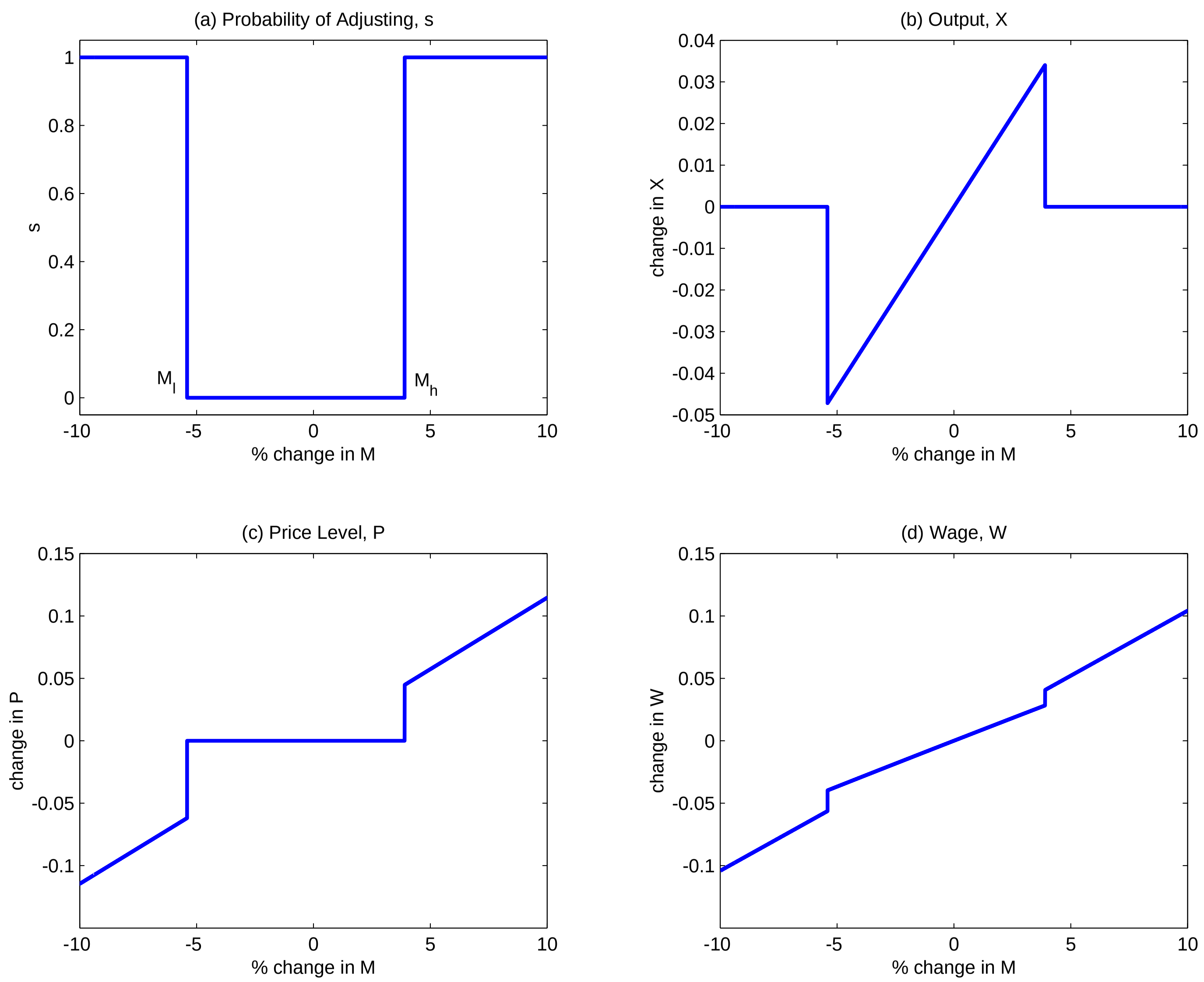
We also look at how the probability of adjusting, s, and output respond to exogenous money shocks when the elasticity of real wage with respect to output is less than unity. We use $\phi = 0.7$ and the results are shown in Figure 5.[16] When fixed costs are only 1 percent of the firm's steady-state revenue, firm i increases its price when the positive money shock is greater than +3.90%, and lowers its price when the negative shock is greater than -5.41%. These values are the same as those of the benchmark when $\phi = 1$; however, the difference is that when $\phi = 0.7$, firm i does not have any uncertainties in its price-adjusting decision.[17] Firm i either adjusts in response to large (positive and negative) shocks with probability $s = 1$, or does not adjust with $s = 1$. Firm i follows pure strategies in its pricing decision. As a result, either no firm adjusts so that prices are sticky in the economy when the magnitude of shocks is between (-5.41%, +3.90%), or all firms adjust when shocks lie outside this range.

When we compare Table 1(b) to 1(a), we find that the presence of real rigidities increases the standard deviations of price level for ±5% and ±10% monetary shocks. With low fixed costs of adjustment, the economy moves from $\bar{P}$ to $\tilde{P}$ instantaneously when the monetary shocks exceed the threshold levels. The lack of mixed strategies induces larger deviations in output and price adjustments.

[16] Lower values of ϕ also produce the same qualitative results. For illustrative purpose, we choose $\phi = 0.7$.

[17] This is because in the specification of our model, change in ϕ does not affect the $\Delta(M|_{s=1})$ curve while the $\Delta(M|_{s=0})$ curve becomes flatter. With low fixed costs of price adjustment, $\Delta(M|_{s=1})$ always outweighs the $\Delta(M|_{s=0})$, and every firm expects other firms will adjust in face of a negative shock as long as the net gain is positive.

Figure 5: Responses to Monetary Shocks: Low ϕ; $\phi = 0.7$, $\kappa = 1\%$ SS revenue



(3) Fixed price-adjusting costs

To illustrate the effects of fixed cost of price adjustment on firm's pricing decision, we now increase the fixed cost of price adjustment to 5 percent of firm's steady-state revenue. Figure 6 shows the firm i's pricing decision and the response of aggregate output when the fixed costs are high. The upper panels, (a) and (b), show the case when $\phi = 1$. With high fixed cost of price adjustment, firm i does not adjust its price unless positive money shocks are greater than +7.66%. For negative shocks, it only adjusts if the shocks are more negative than -20.47%. The lower net gain from price adjustment due to the higher fixed adjustment cost increases the degree of price rigidity in the economy. In addition, with higher fixed adjustment cost, firms' responses to positive and negative shocks become more asymmetric: all firms only adjust when the (absolute) magnitude of negative shock is 12.81% higher than that of a positive shock (compare to 1.51% when κ is only 1 percent of the steady-state revenue).

Higher fixed adjustment cost also leads to a greater range of negative money shocks, (-20.47%, -8.62%), that gives $s \in (0, 1)$. With high cost of price adjustment, fewer firms have the incentive to adjust for a given magnitude of negative shock since the net gain from adjusting decreases. Price level falls by a smaller magnitude, and firm i gains less from price adjustment via the effect of strategic pricing interaction. As a result, the economy does not have full price flexibility for a larger range of negative shocks, and all firms lower their prices only for a greater magnitude of negative shocks. The distribution of price level in Table 2(a) illustrates this result numerically.

Figure 6: Responses to Monetary Shocks: High Fixed Cost; $\kappa = 5\%$ SS revenue

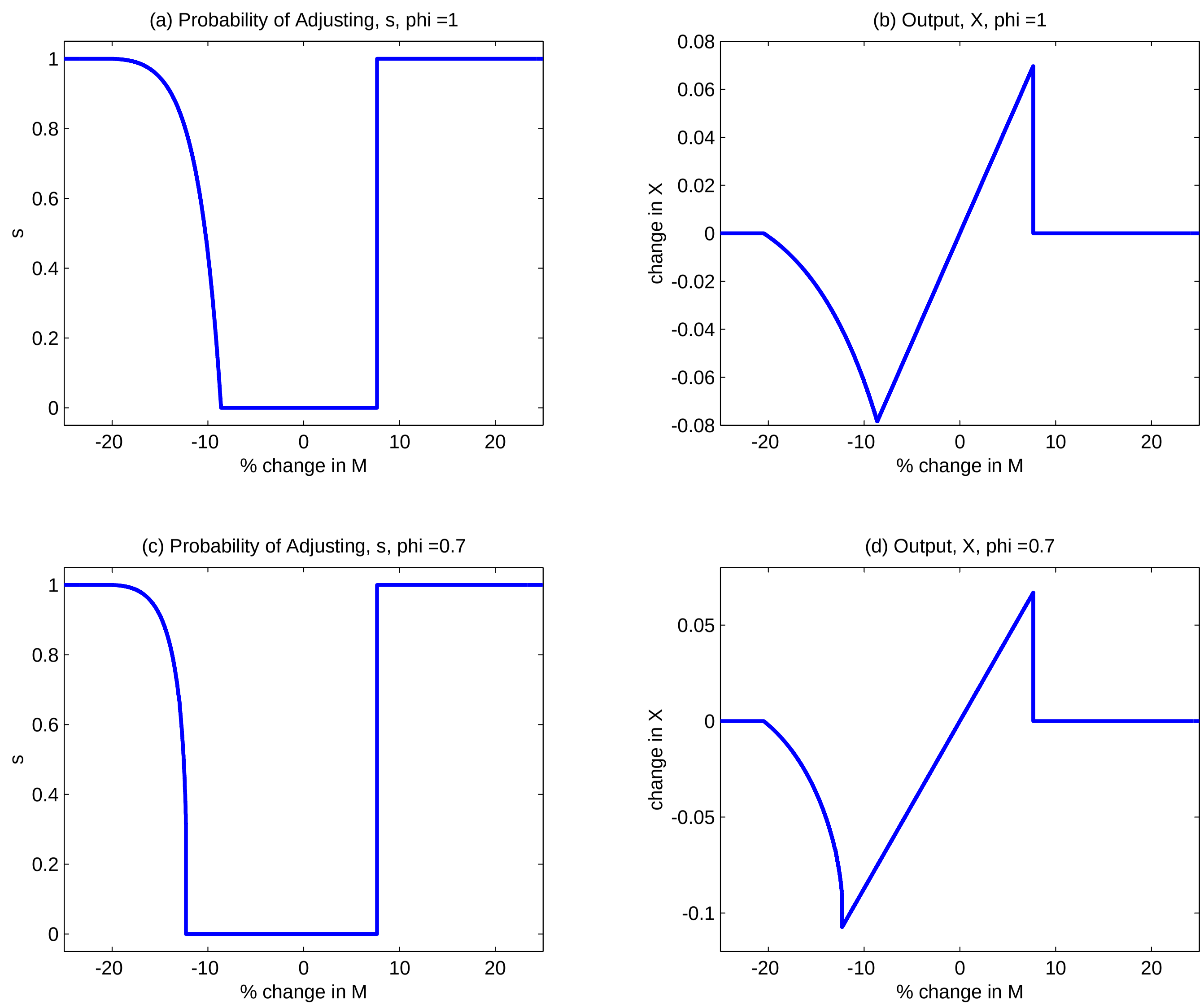


Table 2: High Cost of Price Adjustment, 5% of Steady-State Revenue
($\lambda = 11$)

(a) Benchmark ($\phi = 1$):

M shocks	-1%	$+1\%$	-5%	$+5\%$	-10%	$+10\%$
$E(X)$	0.9046	0.9136	0.8864	0.9318	0.8657	0.9358
σ_X	0.0026	0.0026	0.0131	0.0131	0.0236	0.0230
$E(P)$	1.1	1.1	1.1	1.1	1.0561	1.1466
σ_P	8.66×10^{-15}	8.66×10^{-15}	4.49×10^{-14}	4.49×10^{-14}	0.0142	0.0413

(b) $\phi = 0.7$:

M shocks	-1%	$+1\%$	-5%	$+5\%$	-10%	$+10\%$
$E(X)$	0.8683	0.8771	0.85099	0.8945	0.8291	0.8983
σ_X	0.0025	0.0025	0.0126	0.0126	0.0252	0.0220
$E(P)$	1.1459	1.1459	1.1459	1.1459	1.1459	1.1695
σ_P	4.44×10^{-16}	4.44×10^{-16}	5.00×10^{-14}	5.00×10^{-14}	2.03×10^{-13}	0.0430

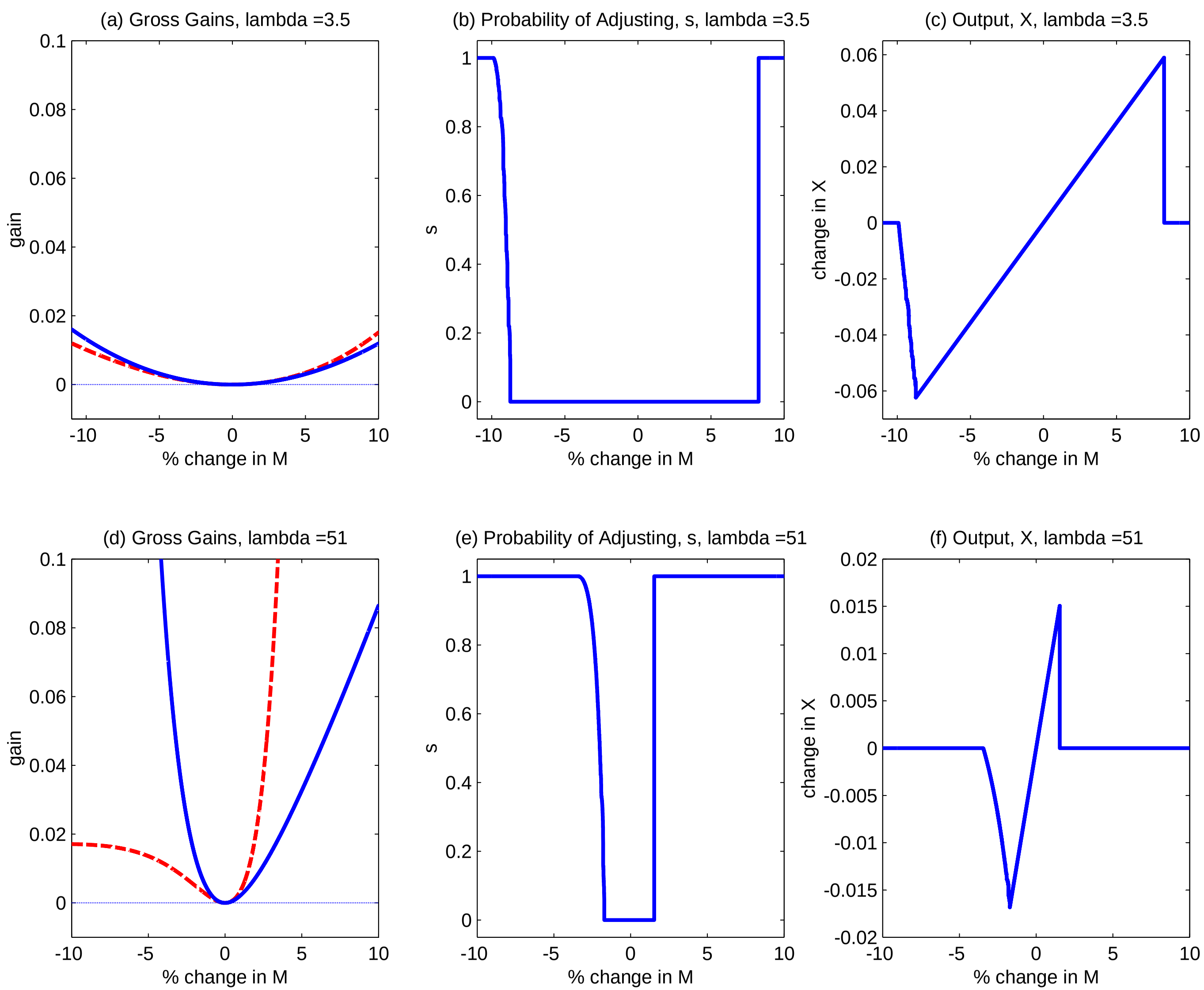
As we have mentioned before, when the elasticity of real wage with respect to output is less than unity, either all firms adjust or none adjusts when the fixed adjustment cost is low. However, with a higher fixed cost of price adjustment, a range of negative money shocks that yields less than full price flexibility in the economy exists. Firm i chooses mixed strategies when shocks lie within this range. We can see from panel (c) of Figure 6 that when shocks are in the range of (-20.47%, -12.29%), firm i's probability of adjusting its price is between 0 and 1, and the fraction of firms in the economy that adjust is less than unity. Output falls by a smaller amount in response to negative shocks when s is getting larger, and this is shown in panel (d). Firms only adjust their prices in response to larger shocks when the cost of price adjustment is high. Table 2(b) shows that firms do not adjust even for a -10% shock. Firms have less incentive to adjust as gains from adjusting decrease, and their pricing decisions more depend on other firms' behaviour. The effect of strategic substitutability becomes more significant when the fixed adjustment cost is high. Therefore, for some range of negative shocks, some firms adjust and some remain sticky ex-post.

(4) Firm's market power

We also examine the effect of firm's market power on its pricing decision. We find that with more market power, a firm tends to have smaller incentive to adjust its price in response to monetary shocks, while it has a larger incentive to adjust when the market competitiveness increases. Figure 7 and Table 3 illustrate this result with fixed cost equals to 1 percent of the steady-state revenue and $\phi = 1$. Panel (a) to (c) of Figure 7 show the case when firm i has a large market power, which is represented by a high firm's price markup;[18] in particular, we have price markup equals to 40 percent of the firm's marginal cost (that is, $\lambda = 3.5$). With a larger market power, firm's gross gain from price adjustment is smaller, and this is represented by the flatter gross gain functions in panel (a). When other firms in the economy do not lower their prices in face of negative monetary shocks, firm i also has a small incentive to reduce its price. Firm i's own price adjustment can lower the aggregate price level because of its market power, which lessens the gain from lowering prices. As a result, the effect of strategic substitutability in pricing decision becomes smaller. We can see from panel (b) that firm i only adjusts in response to larger positive and negative monetary shocks: +8.26% and -9.92%, and its price remains sticky for a larger range of monetary shocks (from -8.74% to +8.26%). Market power tends to increase the price stickiness in the economy, and this finding is consistent with the result of John and Wolman (2008).

[18]Managerial economics uses Lerner Index, $L = 1/\lambda$, to measure a firm's market power. When $L = 0$, the market is competitive and the firm has no market power, while $L \to 1$ implies the firm has larger market power.

Figure 7: Responses to Monetary Shocks: Effects of Market Competitiveness



Dashed Line: gain when s = 1; Solid line: gain when s = 0.

Table 3: Market Power
($\phi = 1$, $\kappa = 1\%$ of steady-state revenue)

(a) $\lambda = 3.5$ (40% price markup:

M shocks	-1%	$+1\%$	-5%	$+5\%$	-10%	$+10\%$
$E(X)$	0.7107	0.7179	0.6964	0.7321	0.6836	0.7386
σ_X	0.0021	0.0021	0.0103	0.0103	0.0181	0.0191
$E(P)$	1.4	1.4	1.4	1.4	1.3873	1.4223
σ_P	1.27×10^{-14}	1.27×10^{-14}	1.13×10^{-13}	1.13×10^{-13}	0.0359	0.0486

(b) $\lambda = 51$ (2% price markup):

M shocks	-1%	$+1\%$	-5%	$+5\%$	-10%	$+10\%$
$E(X)$	0.9755	0.9853	0.9751	0.9827	0.9778	0.9816
σ_X	0.0028	0.0028	0.0053	0.0042	0.0046	0.0032
$E(P)$	1.02	1.02	0.9987	1.0431	0.9711	1.0698
σ_P	1.24×10^{-14}	1.24×10^{-14}	0.0184	0.0176	0.0322	0.0312

In a more competitive environment, the effect of strategic substitutability becomes larger. Panels (d) to (f) show the case when firm's markup is only 2 percent of its marginal cost. With negative money shocks, firm i has a large incentive to adjust when other firms do not adjust (the steep solid line in panel (d)). When firm i lowers its price, its demand increases by a large amount as goods are more substitutable among each other, and hence, firm i can increase profits by lowering its price. With a smaller market power, firm i has a larger incentive to adjust in response to money shocks, and the range of sticky price is narrower (from -1.72% to +1.53%). The firm finds that it is profitable to increase its price when the money shock is only +1.53%, and to lower its price when the shock is -3.44%. Therefore, prices are more flexible in the economy when the market is more competitive.

5 Concluding remarks

Business cycle asymmetries have been widely discussed in recent economic studies. Evidence suggests that the economy responds to monetary shocks asymmetrically. This raises the concern about the effectiveness of monetary policies when the economy is at different phrases of the business cycle.

This paper develops a simple one-period state-dependent pricing model to study the strategic interactions in firms' pricing decisions, and we show that strategic complementarity and substitutability in pricing decision can explain the asymmetric responses of the economy to monetary shocks. We find that the effects of monetary shocks are asymmetric: firms have a larger incentive to increase their prices in response to positive money shocks, and have a smaller incentive to lower their prices with negative shocks of the same magnitude.

This simple model also allows us to examine the mixed strategies that a firm chooses in response to some range of negative shocks. We find that an individual firm's mixed strategies in its pricing decision depend on the magnitude of the shocks, as well as on the proportion of price-adjusting firms in the economy. In addition, when a firm's marginal cost has some real rigidity, the firm only chooses to adjust or remain sticky with certainty if the fixed adjustment cost is low.

We may extend the model to a dynamic setting and use it to see how well it matches the data. The mixed strategies analysis may become more complicated as the firm's future decisions must be taken into account. To match the observation that prices are revised upward more frequently but in smaller magnitude than they are revised downward, we also have to take the heterogeneous menu costs into consideration.

Appendix

A. Proof of Proposition 1

Proof. For region I, $\Delta(M|_{s=1}) > \kappa$, firm i's net gain from price adjustment is positive when $s = 1$. In this region, $\Delta(M|_{s=0}) < \kappa$, but $s = 0$ is not sustainable as every firm expects other firms to adjust after the shocks. To avoid loss in possible gain from price adjustment, a marginal firm i will choose to adjust and we have $s = 1$.

For region II, since $\forall s$, $\Delta(M, s) < \kappa$ when $M \in [M_l, M_h)$. Firm i's net gain from price adjustment is negative, and hence, it will not adjust its price ex-post. Therefore, $s = 0$.

For region IV, the results follow from equation (2.8) that $\forall s$, $\Delta(M, s) > \kappa$, firm i's net gain from price adjustment is positive. Then it decreases its prices in response to negative shocks with probability 1.

For region III, suppose M' lies between M_{ll} and M_l such that: $M_{ll} < M' < M_l < \bar{M}$. We already have $\Delta(M \leq M_{ll}, s) > \kappa$, $\Delta(M \in (M_l, \bar{M}), s) < \kappa$, and given $\Delta(M)$ is continuous and concave up (convex) with $\Delta(\bar{M}) = 0$.[19] Then $\exists\ M' \in (M_{ll}, M_l)$ such that $\Delta(M', s) = \kappa$.

Since M_{ll} is the intersect of $\Delta(M|_{s=1})$ and κ, then $\Delta(M_{ll}|_{s=1}) = \kappa$. Similarly, $\Delta(M|_{s=0})$ and κ intersect at M_l, then $\Delta(M_l|_{s=0}) = \kappa$. The convexity and continuity of Δ imply:

$$\Delta(M'|_{s=1}) < \kappa \quad \textit{and} \quad \Delta(M'|_{s=0}) > \kappa$$

Therefore, for a given M', $\exists\ s \in (0, 1)$ such that $\Delta(M'|_{s\in(0,1)}) = \kappa$.

□

[19] $\Delta(\bar{M}) = 0$ can be shown using equations (2.6) and (2.7).

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