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ABSTRACT

Predetermined Prices and the Persistent Effects of Money on Output*

This Paper illustrates a model of predetermined pricing based on the work of Fischer (1977), where firms set a fixed schedule of nominal prices at the time of price readjustment. This type of price-setting specification cannot produce any excess persistence in a fixed duration model of staggered prices. But we show that with a probabilistic model of price adjustment, as in Calvo (1983), a predetermined pricing specification can produce excess persistence. Moreover, in response to a money shock, the aggregate dynamics are very similar to those under a specification of fixed prices, the assumption underlying most recent dynamic sticky-price models.

JEL Classification: E31 and E32
Keywords: money shocks, predetermined prices and sticky prices

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NON-TECHNICAL SUMMARY

This Paper develops a simple dynamic model of aggregate price and output adjustment under predetermined prices (PP), where firms may set different prices for each future period in which prices are preset. We contrast this with the standard specification, in which a single price is set for all future periods (fixed prices or FP). In our framework, both types of pricing arrangements involve price adjustment according to the probabilistic model of Calvo, in which firms face an exogenous constant probability of readjusting their prices. Conventionally, it is argued that the PP pricing model does not allow for excess persistence, in the sense that the real effects of money shocks cannot persist at a higher rate than that implied by the exogenous frequency of price adjustment. In contrast, it is well known that the FP model can allow for excess persistence in the presence of *real rigiditie*s. Our results, however, show that the same property holds for the PP model. In the presence of real rigidities, the response to money shocks can display excess persistence, even though firms may set different prices for each future period during the life of the price contract. The critical difference between our results and previous versions of the PP model lies in the use of the Calvo (1983) specification for price adjustment.

Our results show that for a special case in which the elasticity of real marginal cost to output is unity (and money follows a random walk), the two pricing specifications are exactly equivalent. More generally, in the response of the price level and output to money shocks, the two specifications are quantitatively very similar. When the degree of real rigidity is very high, the FP specification displays considerably more persistence in the real effects of money shocks, although the PP specification implies a greater impact effect on output. When the degree of real rigidity is low, the opposite conclusion holds.

The two price adjustment specifications reflect different views of the underlying source of price stickiness. If menu costs were the most important cause of price stickiness, then firms would wish to set a single price pertaining to current and future periods. Alternatively, if contracting costs are more important then firms would be more willing to allow for prices to be predetermined but different for future periods, reflecting their expected marginal costs in each period.

Section 1. Introduction

This paper develops a simple dynamic model of aggregate price and output adjustment under predetermined prices (PP), where firms may set different prices for each future period in which prices are pre-set.[1] We contrast this with the standard specification, in which a single price is set for all future periods (fixed prices or FP). In our framework, both types of pricing arrangements involve price adjustment according to the probabilistic model of Calvo (1983), in which firms face an exogenous constant probability of readjusting their prices. Conventionally, it is argued that the PP pricing model does not allow for excess persistence, in the sense that the real effects of money shocks cannot persist at a higher rate than that implied by the exogenous frequency of price adjustment (e.g. Romer 2000). In contrast, it is well known (Taylor 1980, Ball and Romer 1990, Walsh 1998, and Romer 2000, Jeanne 1998, Erceg 1997) that the FP model can allow for excess persistence in the presence of *real rigidities*.[2] Our results, however, show that the same property holds for the PP model. In the presence of real rigidities, the response to money shocks can display excess persistence, even though firms may set different prices for each future period during the life of the price contract. The critical difference between our results and previous versions of the PP model lies in the use of the Calvo (1983) specification for price adjustment[3].

Our results show that for a special case in which the elasticity of real marginal cost to output is unity (and money follows a random walk), the two pricing specifications

[1] This is sometimes referred to as the Fischer model, based on Fischer (1977).
[2] Following Ball and Romer (1990), we define a *real rigidity* to be any mechanism that causes firms to be reluctant to adjust their price relative to the average prices of all other firms in the market.

are exactly equivalent. More generally, in the response of the price level and output to money shocks, the two specifications are quantitatively very similar. When the degree of real rigidity is very high, the FP specification displays considerably more persistence in the real effects of money shocks, although the PP specification implies a greater impact effect on output. When the degree of real rigidity is low, the opposite conclusion holds.

The two price adjustment specifications reflect different views of the underlying source of price stickiness. If menu costs were the most important cause of price stickiness, then firms would wish to set a single price pertaining to current and future periods. But alternatively, if contracting costs are more important (as in the original Fischer (1977) model), then firms would be more willing to allow for prices to be predetermined but different for future periods, reflecting their expected marginal costs in each period.

The next section develops the model. Section 3 illustrates our results. A conclusion then follows.

Section 2: A model of predetermined prices

The main elements of dynamic sticky-price economies are very familiar (see Walsh 1998 for many references). Here we set out the minimum structure that is necessary to compare the two different price setting specifications discussed in the introduction. This class of models can be derived quite easily from an underlying dynamic general equilibrium environment (again, see Walsh 1998).

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[3] Kiley (1999) has contrasted the important differences between price-setting models that use the Calvo specification, equivalent to partial adjustment models, and the staggered price setting model of Taylor (1979). We discuss the significance of this distinction for the PP price setting model more fully below.

Under each pricing specification, firms set prices in advance based on desired or target prices. Desired prices depend on expected marginal cost, which itself depends upon both current output (or the output gap), and prices of all other firms (or the price level). A simple quantity theory equation relates output to the economy-wide price level.

The quantity theory equation (or the aggregate demand equation) is written in log terms as

(1) $$y_t = m_t - p_t,$$

where y_t is aggregate output and $m_t - p_t$ represents real balances. The nominal marginal cost facing each firm is the same function of the aggregate price level and output. It may be written as

(2) $$w_t = p_t + \upsilon y_t.$$

The parameter υ measures the elasticity of the real wage to output.

The desired price of any firm is just the marginal cost in any period. Using (1) and (2), we write the desired price level as

(3) $$p_t^* = (1-\upsilon)p_t + \upsilon m_t.$$

Equation (3) says that the desired price level is equal to an average of the economy-wide price level and nominal aggregate demand. The parameter υ captures the extent to which the desired price level depends on aggregate demand, relative to the current economy-wide price level. The higher is υ, the more sensitive is marginal cost to movements in output (or the output gap), and the more willing individual firms will be to adjust their desired price, relative to the aggregate price level (the average prices of all other firms). But when υ is very small, marginal cost is very insensitive to output, and firms desired prices are very close to the aggregate price level. In this case, firms are extremely reluctant to set prices that differ from the average prices of other firms in the economy. This is the case where there is significant *real rigidity*, in the terminology of Ball and Romer (1990) and Romer (2000).

We now focus on the pricing decision for the representative firm. Let firms face the constant discount factor, $\beta < 1$. Then a firm that must set its price in advance experiences a loss in expected profits, relative to a situation where price adjustment is instantaneous. Following Walsh (1998), it may be shown that the loss in profits is approximately given by the squared deviation of the log price from the desired log price. Thus, any firm *i* faces an expected loss of

(4) $$L_t(i) = E_t \sum_{j=0}^{\infty} \beta^j \Phi(p_{t+j}(i) - p_{t+j}^*)^2$$

where Φ is a constant. Loss function (4) must hold irrespective of the pricing regime that holds.

Fixed prices

We now assume that nominal prices must be set in advance, as in Taylor (1980), Calvo (1983), Yun (1995), and many others. We denote this specification as one of fixed prices (FP). In addition, we follow Calvo (1983) and Yun (1995) in assuming that at the time of price setting is random for each firm. A firm may revise its price in each period with probability $(1-\kappa)$, irrespective of how long its price has been fixed for in the past. When adjusting its price at time t, the firm must set a fixed price $\hat{p}_t(i)$ that then holds for future periods until it faces an opportunity to revise its price again. The firm then faces an expected loss function given by

(5) $$L_t(i) = E_t \sum_{j=0}^{\infty} (\beta\kappa)^j \Phi(\hat{p}_t(i) - p_{t+j}^*)^2 .$$

It is easy to establish that the optimal price for firm *i* is

$$(6) \qquad \hat{p}_t(i) = (1-\beta\kappa)E_t\sum_{j=0}^{\infty}(\beta\kappa)^j p^*_{t+j} \; .$$

At any time period, a fraction $(1-\kappa)$ of firms will re-set their price. Since all firms are alike, they set their price equal to the right hand side of (6). The aggregate price level for the economy is then given by

$$(7) \qquad p_t = (1-\kappa)\,\hat{p}_t + \kappa\, p_{t-1}.$$

From (6), the newly set price $\hat{p}_t$ satisfies

$$(8) \qquad \hat{p}_t = (1-\beta\kappa)\, p^*_t + E_t\beta\kappa\,\hat{p}_{t+1}.$$

We may combine (3), (7) and (8) to solve for the dynamics of p_t, $\hat{p}_t$, and p^*_t for an economy with fixed prices. The solution requires an assumption on the stochastic process determining nominal aggregate demand.

Predetermined prices

Now assume that each firm faces the same constant probability $1-\kappa$ of revising its price, but when it does adjust price, it may set a sequence of prices $\left\{\hat{p}_{t+j}\right\}_0^{\infty}$, for all periods in the future. Beginning the next period, it will again face a constant probability of adjusting its prices. Thus the key difference between this and fixed pricing is that the firm can set a different price pertaining to all future periods. We denote this specification as one of predetermined prices (PP). The assumptions accord with the price setting model of Fischer (1977) (see Romer (2000) for a discussion).

Under this price setting arrangement, when setting a price sequence, the expected loss function of the firm is given by

(9) $$L_t(i) = E_t \sum_{j=0}^{\infty} (\beta\kappa)^j \Phi(\hat{p}_{t+j,t}(i) - p^*_{t+j})^2 ,$$

where $\hat{p}_{t+j,t}(i)$ is defined as the price set by firm *i*, at time *t*, pertaining to time period *t+j* in the future.

The optimal price sequence for firm *i* is

(10) $$\hat{p}_{t+j,t}(i) = E_t p^*_{t+j} .$$

At time period *t*, $1-\kappa$ firms will re-set their prices. All firms set the same price sequence, given by the right hand side of (10).

The aggregate price level for the economy with predetermined prices is given by

(11) $$p_t = (1-\kappa)\sum_{j=0}^{\infty} (\kappa)^j E_{t-j} p^*_t .$$

Equation (11) indicates that the price at any time *t* depends on a weighted sum of prices set this period and in the past, where in each case, the price is equal to the expected *desired* price, based on the information available at the time of price adjustment.

Using equations (3) and (11) we may obtain the solution for actual and desired aggregate prices for the economy with predetermined prices.

Monetary process

In order to compare the effects of the two pricing regimes, we must make an assumption about the stochastic process for the money stock. Assume that the money stock exhibits an AR(1) process in growth rates. Thus

(12) $$m_t - m_{t-1} = \rho(m_{t-1} - m_{t-2}) + u_t ,$$

where $u_t \sim iid(0,\sigma^2)$. There is no drift in the money stock.[4]

[4] The introduction of drift in the monetary process would lead to a distinction between the FP pricing and the PP pricing, since the second pricing arrangement can costlessly adjust prices for expected monetary growth, while the former cannot. But a more realistic approach to FP pricing in the presence of expected

Section 3. A comparison of the PP and FP specifications.

Solution: fixed prices

Under the fixed pricing regime, we may solve equations (3) (7), (8) and (12) to obtain

(13) $$p_t = \mu p_{t-1} + (1-\mu) m_t + \frac{\rho\beta\mu(1-\mu)}{(1-\rho\beta\mu)}(m_t - m_{t-1}),$$

where μ is the stable root of the dynamic system in $\tilde{p}_t$ and p_t implied by (3), (7), (8) and (12).[5]

Then, using (1), we write output as

(14) $$y_t = \mu y_{t-1} + \mu u_t + \mu\rho(1 - \frac{\beta(1-\mu)}{(1-\rho\beta\mu)})(m_t - m_{t-1}).$$

Solution: predetermined prices

Under the predetermined pricing regime, we may write the expression for the aggregate price level as

(15) $$\begin{gathered} p_t = (1-\kappa)\sum\nolimits_{j=0}^{\infty} \kappa^j E_{t-j}((1-\upsilon)p_t + \upsilon m_t) = \\ (1-\kappa)(1-\upsilon)\sum\nolimits_{j=0}^{\infty} \kappa^j E_{t-j} p_t + (1-\kappa)\upsilon \sum\nolimits_{j=0}^{\infty} \kappa^j m_{t-j} \end{gathered}$$

The general solution to equation (15), using (12), may be shown as

(16) $$p_t = \sum\nolimits_{j=0}^{\infty} \theta(j) u_{t-j}$$

where

$$\theta(j) = \frac{(1-\rho^{j+1})\upsilon(1-\kappa^{j+1})}{(1-\rho)(1-(1-\kappa^{j+1})(1-\upsilon))}.$$

inflation, utilized by Yun (1995), is to assume that firms can add a deterministic trend to their newly set price, based on expected trend inflation. If we use this interpretation of the FP model, then the two pricing regimes would treat trend inflation in identical ways. Hence, there is no loss of generality in omitting a drift term in equation (12).

Then, the level of output may be obtained from equation (1) together with (16).

Equivalence of the two pricing schemes

The first result to note is that when $\upsilon = 1$, and $\rho = 0$ the solutions for (13) and (16) are equivalent. When $\upsilon = 1$, and $\rho = 0$, we obtain $\mu = \kappa$, so from (13), we have

(17) $p_t = \kappa p_{t-1} + (1-\kappa) m_t$

and

(18) $y_t = \kappa y_{t-1} + \kappa u_t$.

From (16), noting that when $\rho = 0$, we have $m_t = \sum_{j=0}^{\infty} u_{t-j}$, and the solution (17) and (18) also follow. Thus, when the elasticity of marginal cost to output is unity and the money stock follows a random walk, both pricing regimes have the same aggregate price dynamics, and therefore the same behavior for aggregate output. In this case, the dynamics of the price level and output are driven purely by the probability of price adjustment. A shock to the money stock at time *t*, u_t, is absorbed into the aggregate price level up to the proportion $1-\kappa^T$ after T periods. Therefore, there is no persistence beyond that imparted by the probability distribution of price adjustment itself.

However, when $\upsilon \neq 1$, the two pricing regimes have different implications for the dynamics of prices and output. For simplicity, we continue to assume that $\rho = 0$ for now. The dynamics of the price level and output under fixed prices are well known (see Chari et al (2000), Romer (2000), Walsh (1998)). In particular it is easy to show that

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[5] The expression for μ is $\mu = \frac{1}{2}\left(1-\upsilon+\kappa\upsilon+\frac{\kappa(1-\upsilon)+\upsilon}{\beta\kappa} - \sqrt{(1-\upsilon+\kappa\upsilon+\frac{\kappa(1-\upsilon)+\upsilon}{\beta\kappa})^2 - \frac{4}{\beta}}\right)$.

$\mu > \kappa$ $(\mu < \kappa)$ as $\upsilon < 1$ $(\upsilon > 1)$.[6] In the first case, prices converge at a rate slower than that dictated by the exogenous frequency of price adjustment. As a consequence, there is more persistence in output than that imparted by the exogenous price adjustment process. This excess persistence is driven by the presence of real rigidity. On the other hand with $\upsilon > 1$, prices adjust more quickly and there is less persistence in output than that imparted by the exogenous price adjustment process.

In the conventional version of the predetermined pricing model, as presented by Romer (2000), there can be no excess persistence at all. For instance, when price contracts are adjusted every two periods and price setters can set different prices for each period, an unanticipated money shock can have an impact on output that lasts at most two periods. Once all contracts have been readjusted, the price level must fully adjust to a money shock.

The predetermined pricing model here does allow the possibility of excess persistence, in the sense that the price level may adjust at a slower rate than that imparted by the exogenous price adjustment probability. To see this, note that a permanent shock to the money shock at time *t* will increase the price level by $\frac{\upsilon(1-\kappa^T)}{(1-(1-\kappa^T)(1-\upsilon))}$ after *T* periods. This is less than (greater than) $(1-\kappa^T)$ as $\upsilon < 1$ $(\upsilon > 1)$. Thus, the condition for excess persistence in response to money shocks in the predetermined price model is equivalent to that in the fixed price model.

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[6] To see this, let $a = 1 - \upsilon + \kappa\upsilon + \frac{\kappa(1-\upsilon)+\upsilon}{\beta\kappa}$, then from footnote 2 it follows that $\mu(\upsilon) = \frac{1}{2}\left(a - \sqrt{a^2 - \frac{4}{\beta}}\right)$, where $\mu(\upsilon)$ reflects the dependence of the root on υ. Note that

The difference between these results and previous versions of the PP model lies in the features of the probabilistic price adjustment process of Calvo (1983). When all prices readjust after a known duration, then price setters under a PP regime will take into account that the prices of all other firms will have adjusted to the information available at the outset of the oldest contract. But under the Calvo price setting arrangement, all contracts are readjusted only asymptotically. Even though only a small fraction of contracts are unadjusted after the average contract length ($\frac{1}{1-\kappa}$) has elapsed, this can be an important determinant of the speed of aggregate price adjustment. This will be the case when the adjusting firms are unwilling to allow their prices to differ from those of all other firms (i.e. when υ is small). Thus, the presence of real rigidity can generate excess persistence in output, even in the PP model, when contracts are readjusted in the manner described here[7].

Quantitative analysis

How do the two pricing regimes differ quantitatively? Figures 1 and 2 illustrate the impact of a permanent, unanticipated increase in the money supply on the price level and output under the two specifications. We use three different values for υ. Setting $\upsilon=3$ implies a high elasticity of marginal cost to output, and a low degree of real rigidity. $\upsilon=1.2$ represents the parameterization used in Chari et al. (2000), based on a dynamic general equilibrium version of the Taylor overlapping contracts model. With

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$\mu(1)=\kappa$, and $\mu'(\upsilon)<0$.

[7] Kiley (1999) has noted that sticky price models that follow partial adjustment rules, such as the Calvo model employed here, display aggregate price and output dynamics quite different from the staggered price setting models of Taylor (1979). In particular, the partial adjustment models generate much more inherent persistence, for most parameterizations of the elasticity of real marginal cost. The results here are quite in accordance with Kiley. A model of price setting that generates no excess persistence at all under staggered price setting contains significant persistence under the partial adjustment specification.

υ=0.1 there is a much higher elasticity of marginal cost to output, and a higher degree of real rigidity. These parameter assumptions are contained in range used by Ball and Romer (1990).

Table 1: Calibrated parameter values			
β	κ	υ	ρ
0.985	0.75	3, 1.2, 0.1	0.23

The rationale for the other parameter values chosen is as follows. A value of β of 0.985 implies an annual real interest rate of 6 percent, and κ equal to 0.75 implies an average length of price adjustment of four quarters. Finally, to choose a value of ρ, we directly estimated equation (12) on US Federal Reserve non-borrowed reserve data over the 1959-2000 period. Non-borrowed reserves represents a widely used measure of an exogenous policy-determined monetary aggregate for the US economy.

The figures illustrate that in general, the response of the price level and output is quite similar for the two different pricing schemes. With a very high value of υ, the immediate price impact is greater in the PP specification, and so the impact on output is smaller than in the FP specification. Of course in this case, the overall persistence of output is very low for both specifications, as implied by the discussion above. When $\upsilon = 1.2$, the two specifications display almost identical price and output responses. Finally, when $\upsilon < 1$, the response of price level and output is the reverse of that in the case where $\upsilon = 3$. In Figure 3, we find that the immediate price impact of a money shock is less under PP model than under FP. As a result, the immediate impact on output is larger under PP. But PP displays considerably less persistence. But note that both specifications display considerable *excess* persistence in the case $\upsilon = 0.1$. The output response is initially greater under PP. But after 8 quarters, output under PP falls below that under FP, and adjusts towards its steady state at a much faster pace subsequently.

Section 4. Conclusion

We have introduced a model of *predetermined pricing*, where firms set a fixed schedule of nominal prices at the time of price readjustment, based on the model of Fischer (1977). While this pricing specification cannot produce any excess persistence in a fixed duration model of staggered prices (Romer, 2000), we show that with a probabilistic model of price adjustment as in Calvo (1983), the predetermined pricing specification can produce aggregate persistence. Moreover, the aggregate dynamics in response to a money shock are very similar to those under a specification of *fixed prices*, the assumption underlying most recent dynamic sticky-price models.

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Figure 1a: Price Level v=3

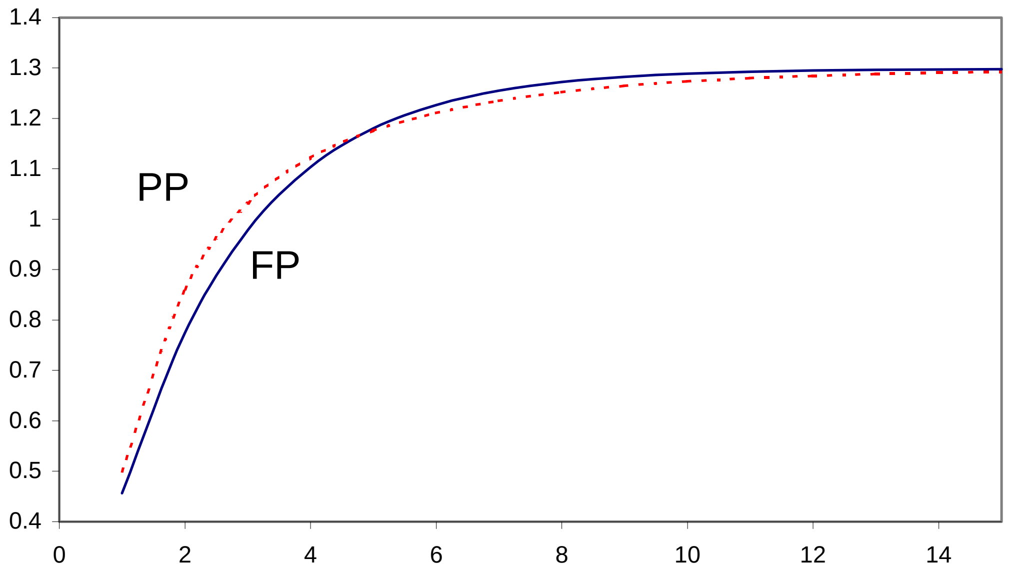

Figure 1b: Output v=3

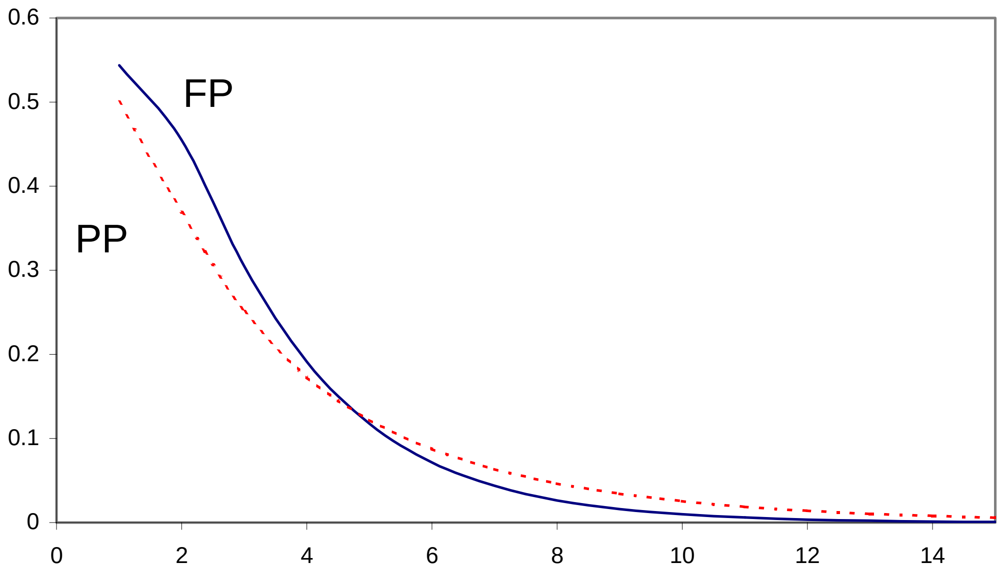


Figure 2a: Price Level v=1.2
1.4
1.2
1
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14

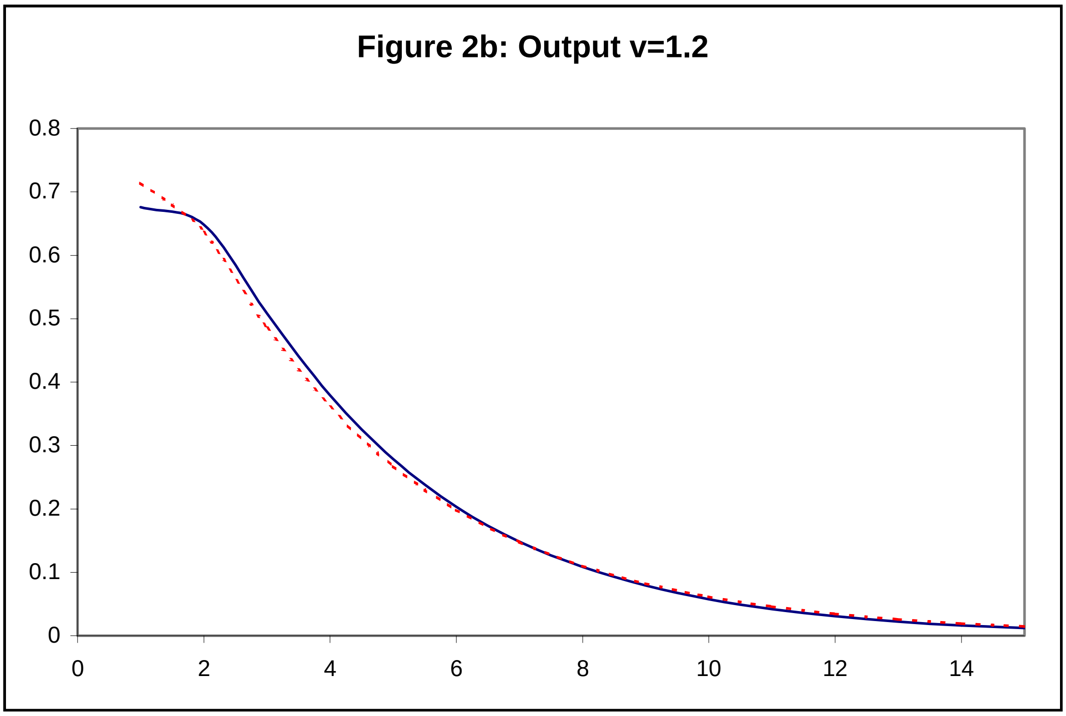
Figure 2b: Output v=1.2
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
2
4
6
8
10
12
14

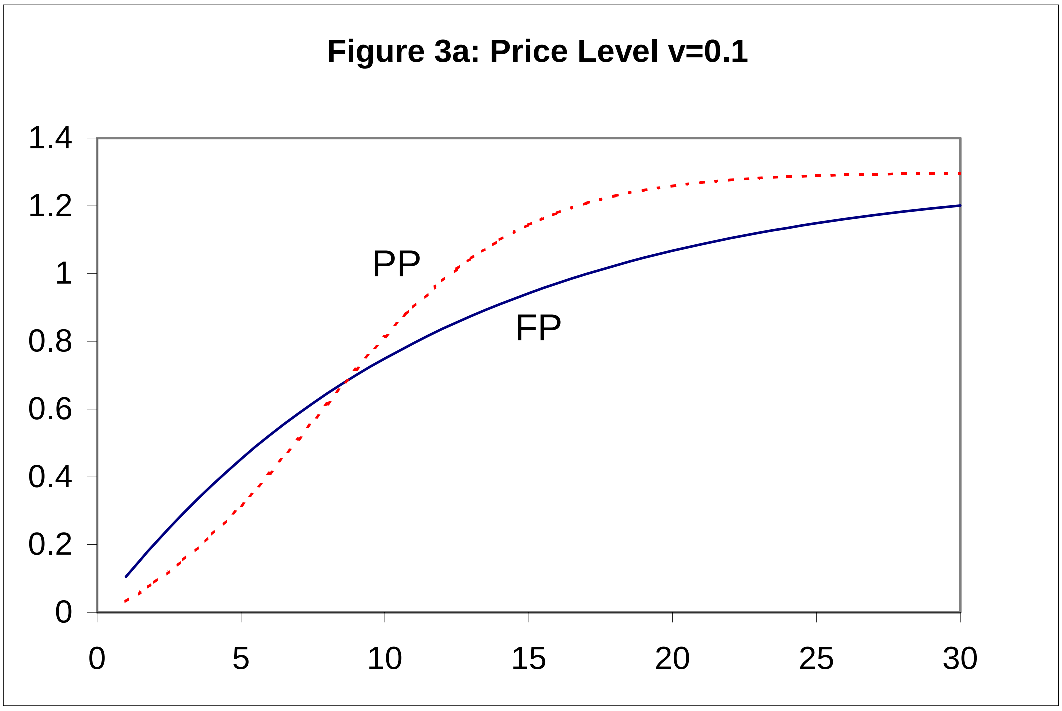
Figure 3a: Price Level v=0.1
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
PP
FP

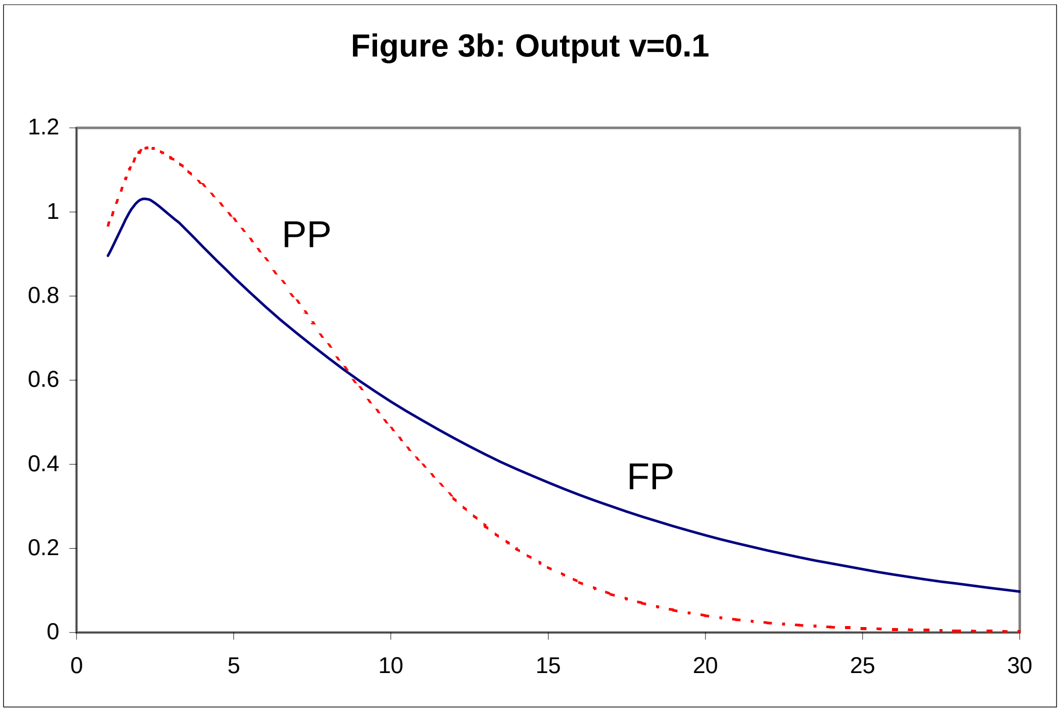
Figure 3b: Output v=0.1
1.2
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
PP
FP