Implications of state-dependent pricing for dynamic macroeconomic models

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Abstract

State-dependent pricing (SDP) models treat the timing of price changes as a profit-maximizing choice, symmetrically with other decisions of firms. Using quantitative general equilibrium models which incorporate a “generalized (S,s) approach”, we investigate the implications of SDP for topics in two major areas of macroeconomic research, the early 1990s SDP literature and more recent work on persistence mechanisms. First, we show that state-dependent pricing leads to unusual macroeconomic dynamics in response to monetary shocks, echoing earlier suggestions: these novel dynamics arise because of the timing of price adjustments chosen by firms. In particular, we display an example in which output responses peak at about a year, while inflation peaks at about two years after the shock. Second, we examine whether the persistence-enhancing effects of two New Keynesian model features, namely specific factor markets and variable elasticity demand curves, depend importantly on whether pricing is state dependent. In an SDP setting, we provide examples in which specific factor markets perversely works to lower persistence, while variable elasticity demand raises it.
1 Introduction

State-dependent pricing models have long been viewed as a desirable vehicle for macroeconomic analysis, because these models treat the timing of price changes as a profit-maximizing choice. SDP models make it possible to explore how the frequency of price changes responds to variations in model features, such as the form of the monetary policy rule, and to develop the implications of altered adjustment timing for the evolution of other macroeconomic variables. Yet, most macroeconomic investigations employ models with time dependent pricing (TDP) for two reasons. First, until recently, it has not been possible to construct operational SDP models, frameworks in which the effects of alternative structural features could be explored or that could be readily taken to the data. By contrast, TDP models have proven to be a workhorse for both of these purposes. Second, macroeconomists have been unsure if incorporating state-dependent pricing behavior would make a significant difference for the implications of economic models: some have speculated that it would be relatively inconsequential in many contexts to adopt SDP rather than the more easily solved TDP model and others have expressed the view that incorporating state-dependence is unnecessary because the frequency of price changes do not vary enough, at least in moderate inflations.2

Using a battery of quantitative general equilibrium models developed along the lines of Dotsey, King and Wolman [1999], we show that SDP modeling makes a difference in terms of model implications within two major areas of macroeconomic literature. First, as suggested by the 1990s SDP literature – which made use of very different models – we show that there can be a quantitatively important effect of state-dependent pricing for economic outcomes under steady inflation and in response to monetary shocks. State-dependent pricing leads to novel macroeconomic dynamics, including a change in the lead-lag structure of output and inflation. In particular, we display an example in which output responses peak at about a year, while inflation peaks at about two years, in line with Friedman’s [1992] summary of dynamic responses for the US and other countries. Such dynamic responses have not previously been obtained in sticky price models, as stressed by Mankiw [2001], and the response depends critically on the price adjustment pattern endogenously chosen by firms. Second, it has been shown that specific factor markets and variable elasticity demand curves generate more persistent output effects of monetary shocks because they moderate the size of price changes that firms make. We investigate whether these results are sensitive to the incorporation of state-dependent pricing. We find that they can be: specific factor markets perversely work to lower persistence in the face of state-dependent pricing, while variable elasticity demand continues to raise it.

1We thank our discussant Susanto Basu for his substantial patience as well as his useful comments and questions. We have also benefitted from valuable comments by Alex Wolman and Pierre Sarte.

2quote from Taylor handbook chapter
The organization of the remainder of the paper is as follows. Section 2 provides a little background on the literatures related to this paper. Section 3 describes the dynamic stochastic general equilibrium (DSGE) models that we employ in the paper. The next two sections of the paper provide our core findings. Section 4 evaluates whether modern quantitative state-dependent models have the four key implications highlighted by the early 1990s SDP literature. Section 5 evaluates the consequences of SDP for the two persistence-enhancing mechanisms stressed by some New Keynesian economists. The common finding of sections 4 and 5 is that state-dependent pricing has a rich set of implications for the dynamics of macroeconomic models which differ substantially from those of time dependent models.

We are pleased to have contributed this work to the April 2004 Carnegie-Rochester conference in honor of Alan Stockman, “The Economics of Exchange Rates” and the resulting conference volume. Comparing our title and that of the conference, a reader may plausibly wonder if there has been some mistake and our paper has accidentally fallen into the wrong collection. But we do not think that Alan will think so, since he has long argued in various conference discussions that it is important to incorporate state-dependent pricing into open economy modeling. In the last decade, research on “the New Open Economy Macroeconomics” has explored the implications of sticky prices for the behavior of exchange rates. That literature has nearly exclusively concentrated on time-dependent pricing models.\(^3\) Our results suggest that the NOEM literature, by concentrating on time-dependent pricing models, may have missed some important dynamic implications of price-stickiness and reached inappropriate conclusions about the implications of structural features of models.

\section{A little background}

We begin by providing a quick overview of the two literatures on which we build.\(^4\)

\subsection{The early 1990s literature on state-dependent pricing}

A decade ago, macroeconomists viewed dynamic models with state-dependent pricing (settings in which firms choose the timing and magnitude of their price adjustments based on the state of the economy) as having very different implications from time-dependent models (settings in which firms choose the magnitude of price adjustment at exogenously specified times). For example, the influential textbook of Blanchard and Fischer [1989] reviewed a number of state-dependent pricing models and stressed how different the conclusions from SDP models were from TDP models, particularly

\(^3\)The only exception that we know is Landry [2003].

\(^4\)A more comprehensive overview is contained in the working paper version of this research, Dotsey and King [2004], which is available at http://people.bu.edu/rking as well as in the NBER and FRB Philadelphia working paper series. The weblink also makes GAUSS and MATLAB code available to those interested in replicating and extending this research.
in terms of the effects of monetary disturbances on real activity. Further contributions, published shortly after the textbook, increased the perceived discrepancy between time and state-dependent pricing models. Taken together, these developments through the early 1990s suggested the following ideas: (1) The steady-state pattern of price adjustment depends importantly on the nature of the demand and cost functions of the firm (Sheshinski and Weiss [1977,1983]); (2) The dynamic effect of money on output within state-dependent pricing models is dramatically different from that in time-dependent models, possibly involving complicated cyclical adjustment processes and nonlinear responses (Caplin and Leahy [1991]); (3) The evolution of the price level is substantially affected by the adjustment strategies of firms interacting with heterogenous prices (Caballero and Engel [1993]); and (4) Multiple equilibria can readily arise in state-dependent pricing models, due to complementarities in price-setting, even with the type of exogenous money stock rule that nearly always guarantees a unique equilibrium in time-dependent models (Ball and Romer [1991]).

Accordingly, our first objective in this paper is to evaluate whether these core ideas remain as features in dynamic general equilibrium analysis, with specific emphasis on the effects of monetary shocks. Using a basic general equilibrium model, we find support for all of the core ideas from the early 1990s SDP literature.\footnote{There is one exception: our use of linear approximation methods makes it impossible for us to explore the implications of nonlinearities.}

### 2.2 Recent work on output responses to monetary shocks

Within the last decade, there has been substantial research into the effects of monetary shocks and monetary policy rules within macroeconomic models that incorporate time-dependent pricing, most frequently along the lines of Taylor [1980] or Calvo [1983]. By contrast, there has been relatively little research on these topics within state-dependent pricing models. Initially, this was because state-dependent pricing models were not operational: it was difficult to solve them under general assumptions about the processes driving economic activity. But the Dotsey, King and Wolman [1999] state-dependent pricing model provides one laboratory where these questions can be addressed.

One major focus of the recent literature on time-dependent models has been a “search for persistence mechanisms”, in response to Chari, Kehoe and McGrattan’s [2000] provocative critique of Taylor-style pricing models. We look at two prominent ideas in the literature on New Keynesian macroeconomics: the idea that there are factor markets that are specific to individual firms (Ball and Romer [1990], Kimball [1995] and Rotemberg [1996]) and the idea that firms may face non-constant elasticity demand curves that are of a “smoothed off kink” form (Ball and Romer [1990] and Kimball [1995]). The basic idea is that each of these mechanisms should moderate the magnitude of price adjustments that a firm would like to make, relative to those
in a benchmark setting with flexible factors and a constant elasticity demand, thus making the price level response more sluggish and the nonneutrality of money more protracted.

In particular, we ask whether these New Keynesian mechanisms lead to increases in persistence that survive the introduction of state-dependent pricing. We find that there are very different conclusions for these two models. Within our state-dependent pricing framework, the introduction of local factor markets leads to more rapid price adjustment in the face of steady-state inflation and also more rapid adjustment in response to monetary shocks. Accordingly, time-dependent models that stress this mechanism are implicitly relying on very large costs of price adjustment in order to generate persistence. The variable demand elasticity specification works quite differently and illustrates an important set of issues about state-dependent pricing models. First, in a steady state, this model produces more rapid adjustment – at given adjustment costs–than its constant elasticity counterpart. Second, in response to a monetary shock, this model produces slower adjustment initially than its constant elasticity counterpart. Taking these two effects together, we find that the variable demand elasticity model enhances persistence in a state-dependent pricing environment.

3 DSGE models

We construct and study four models designed to be representative of much recent work in New Keynesian macroeconomics: production is linear in labor input; consumption and labor effort are separable in utility, and aggregate demand is governed by the quantity theory of money.\(^6\) Thus, the only sophisticated element is the state-dependent pricing mechanism. While use of such simple models is limiting on some dimensions, it allows us to clearly illustrate the implications of state dependence for standard modeling. The four related models are as follows. Model I assumes that there is constant elasticity demand as in Dixit-Stiglitz [1977] and that there is a global labor market, two assumptions that allow for ready aggregation.\(^7\) Model II allows for a variable demand elasticity, structured so that there is a “smoothed off” kink in the demand curve as suggested by Kimball [1995]. Models III and IV assume that there is a local labor market, a device used by authors such as Ball and Romer [1991].

\(^6\)Relative to our work in Dotsey and King (2001), we therefore abstract from investment and capital formation; from variable utilization; and features of household preferences and constraints which rationalize separate choices of hours and employment or provide motivations for simultaneously varying consumption and hours. We also abstract from the structural features that give rise to money demand.

\(^7\)This is a standard set of assumptions in work on quantitative dynamic models beginning with King and Wolman [1996] and Yun [1996]:
3.1 The Demand Aggregator

Firms facing a declining demand elasticity will be less aggressive in pricing, as in the classic textbook discussion of a kinked demand curve. To develop a specific aggregator of the class suggested by Kimball [1995], we consider a general expenditure minimization problem facing households,

$$\min_{\{c(i)\}} \int_0^1 P(i)c(i)di \text{ subject to } \int_0^1 D(c(i)/c)di = 1, \quad (1)$$

where $c$ is the total consumption aggregator implicitly defined by the demand aggregator $D$, which is an increasing concave function, and where $P(i)$ is the nominal price charged by the $i$th firm on the unit interval.

For any such aggregator, the aggregate price level, $P$, is implicitly defined by $\int_0^1 (\frac{P(i)}{P})\left(\frac{c(i)}{c}\right)di = 1$. Expenditure minimization requires that $\frac{1}{P}D'(\frac{c(i)}{c}) = \frac{P(i)}{P}$, where $\Lambda$ is the Lagrange multiplier on the constraint. For aggregators of the Kimball class, the first order condition can be solved to yield demand curves of the form $c(i)/c = d(P(i)/\Lambda)$, where $\Lambda$ is determined by the condition $\int_0^1 D(d(P(i)/\Lambda))di = 1$. Given the demand curve and the multiplier, the aggregate price level index is determined by $\int_0^1 (\frac{P(i)}{P})\left(\frac{c(i)}{c}\right)di = 1$.

Our specific aggregator: We use a functional form for $D$ that generates demand curves which are more elastic for firms that adjust their price than for firms whose relative price declines as a result of price fixity,

$$D(x) = \frac{1}{(1+\eta)^{\gamma}}[(1+\eta)x-\eta]^\gamma - [1 + \frac{1}{(1+\eta)^{\gamma}}].$$

One nice property of this specification is that the Dixit-Stiglitz aggregator is a special case when $\eta = 0$. The relative demand curves are given by

$$\frac{c(i)}{c} = \frac{1}{1+\eta}\left[(\frac{P(i)}{P})(\frac{P}{\Lambda})^{1/(\gamma-1)} + \eta\right]. \quad (2)$$

i.e., they are the sum of a constant elasticity demand augmented by a constant. The Lagrange multiplier is given by $\frac{\Lambda}{P} = \int_0^1 (P(i)/P)^{\gamma/(\gamma-1)}di[\gamma-1]^{\gamma-1}/\gamma$. Conveniently, the aggregate price level index can be written as

$$P = \frac{1}{1+\eta}\left[\int_0^1 P(i)^{\gamma/(\gamma-1)}di[\gamma-1]^{\gamma-1}/\gamma\right] + \frac{\eta}{1+\eta}\int_0^1 P(i)di. \quad (3)$$

so that it is the sum of a DS and linear aggregator.

Figure 1 displays examples of the type of demand curves that can be generated with this aggregator. The benchmark case is a Dixit-Stiglitz specification with a demand elasticity of 10 (this involves choosing $\eta = 0$ and $\frac{1}{\gamma-1} = -10$, so that $\gamma = .9$). Over the range of demand plotted here, this curve appears nearly linear to the eye in panel A, but panel B confirms that the demand elasticity is constant. To study
a variable elasticity demand curve, we choose the parameter $\eta$ so that the demand curve has elasticity 10 at $c(i)/c = 1$, with $\gamma$ then controlling the shape of the curve at other points.\textsuperscript{8} In the Figure, we use a value of $\gamma = 1.02$, which means that a 1.5% increase in price yields a 20% decrease in demand, which is intermediate between assumptions made by Kimball [1995] and Bergin and Feenstra [2000]. The marginal revenue schedules are plotted in panel B. The elasticity implications are shown in panel C: with $\gamma = 1.02$, a 20 percent decline in output means that the elasticity rises from 10 to 2.5, while a 10 percent rise in output means that the demand elasticity falls from 10 to 5. Finally, the profit implications at a marginal cost of .9 are shown in panel D.

3.2 Firms

We consider two labor market structures, one with global labor markets and the other where labor is tied to a specific firm. In the latter case, we assume that firms are small when it comes to assessing marginal cost, but large when it comes to pricing.\textsuperscript{9}

3.2.1 Factor demand and marginal cost

Production is linear in labor, $y(i) = an(i)$, where $y(i)$ is the output of an individual firm, $a$ is the level of technology, and $n(i)$ is hours worked at a particular firm. Hence, real marginal cost, $\psi_t$, is given by $\psi_t = w_t/a$ in the case of global factor markets or by $\psi_t(i) = w_t(i)/a$ in the case of specific factor markets.

3.2.2 Price setting

Dotsey, King and Wolman [1999] develop a model of dynamic pricing that can be readily integrated into a general equilibrium model. It also contains time and state-dependent pricing specifications as special cases. Basic features of our approach are: (i) firms are monopolistic competitors, facing demand for their product given by $2$; (ii) within each period, some firms will adjust their price and all adjusting firms will choose the same nominal price $P_t^*$; (iii) the state of the economy includes a discrete distribution of firms, with firms of type $j$ having last set their price $j$ periods ago at the level $P_{t-j}$, so that we refer to $j$ as the vintage of the price and denote the fractions of firms with this price as $\theta_{jt}$ ($j = 1, 2, ..., J$); and (iv) a fraction $\alpha_{jt}$ of vintage $j$ firms decides to adjust its price and a fraction $1 - \alpha_{jt}$ decides not to adjust its price (all vintage $J$ firms choose to adjust).\textsuperscript{10}

The fraction of firms, after adjustment, which have a vintage $j$ price is denoted $\omega_{jt}$ and these fractions play an important role in our analysis because they serve as

\textsuperscript{8} As $\gamma$ approaches 1 from above, the demand curve becomes increasingly more concave.

\textsuperscript{9} The local labor market is not quite the "yeoman farmer" setting, as we allow individual workers to insure against the consumption risks associated with individual market conditions.

\textsuperscript{10} Since all firms are in one of these situations, $\sum_{j=1}^{J} \theta_{jt} = 1$. 

weights in various aggregation contexts. The total fraction of adjusting firms \( \omega_{jt} \) satisfies \( \omega_{jt} = \sum_{j=1}^{J} \alpha_{jt} \theta_{jt} \) and fractions of firms \( \omega_{jt} = (1 - \alpha_{jt}) \cdot \theta_{jt} \) maintain the price that they previously set in period \( t - j \). Using these weights, for example, the perfect price level index is given by

\[
P_t = \frac{1}{1+\eta} \left[ \sum_{j=0}^{J-1} \omega_{jt} P_t(j) \right]^{\gamma/(\gamma-1)} \left[ \sum_{j=0}^{J-1} \omega_{jt} P_t(j) \right]^{1/(\gamma-1)} + \frac{\eta}{1+\eta} \sum_{j=0}^{J-1} \omega_{jt} P_t(j).
\]

Finally, the “beginning of period” fractions are mechanically related to the “end of period” fractions via \( \theta_{j+1,t+1} = \omega_{jt} \) for \( j = 0, 1, ..., J - 1 \).

If the adjustment fractions \( \alpha_j \) are treated as fixed through time, then the model collapses to Levin [1991], so that it contains Calvo [1983] and Taylor [1980] as special cases. In this interpretation, \( \alpha_j \) plays two roles: it is the fraction of firms given the opportunity to adjust within a period and it is also the probability of an individual firm being allowed to adjust after \( j \) periods, conditional on not having adjusted for \( j - 1 \) periods. Under state-dependent pricing we employ randomized fixed costs of adjustment to induce discrete adjustment by individual firms, while allowing for an adjustment rate that responds smoothly to the aggregate state of the economy.

In both the time dependent and state-dependent settings, the firm’s optimal pricing decision can be described using a dynamic programming approach. For example, a firm that last changed its price \( j \) periods ago, must choose between continuing with a fixed nominal price, which implies a relative price of \( p_{jt} = P_t(P_t + 1) \); and paying a fixed cost of adjusting its price (\( \xi \)). Each \( j \)-type firm has a value function of the form

\[
v(p_t, \xi_t, s_t) = \max \{v_{jt}, v_{0t}\} \quad (4)
\]

with

\[
v_{jt} = z(p_{jt}, s_t) + \beta E_t \frac{\lambda_{jt+1}}{\lambda_t} v(p_{j+1,t+1} P_t, \xi_{t+1}, s_{t+1})
\]

\[
v_{0t} = \max_p z(p_t) + \beta E_t \frac{\lambda_{jt+1}}{\lambda_t} v(p_t P_t, \xi_{t+1}, s_{t+1}) - w_t \xi_t
\]

being, respectively, the values if the firm does (\( v_{0t} \)) or does not adjust (\( v_{jt} \)). In these functions and below, \( s_t \) is a state vector that governs the evolution of the firm’s demand and costs and \( \frac{\lambda_{jt+1}}{\lambda_t} \) is the ratio of future to current marginal utility, which is the appropriate discount factor. Real profits are given by \( z(p_{jt}) = [p_{jt} - \psi_{jt}]C_{jt} \).

The dynamic program (4) implies that the optimal price satisfies an Euler equation that involves balancing pricing effects on current and expected future profits. That is, as part of an optimal plan, firms that reset their price will choose a price that satisfies

\[
0 = \frac{\partial z(p_t, s_t)}{\partial p_t} + \beta E_t \left[ \frac{\lambda_{jt+1}}{\lambda_t} \frac{\partial v(p_t P_t, \xi_{t+1}, s_{t+1})}{\partial p_t} \right]. \quad (5)
\]
Furthermore, for any given state of the economy there is a unique cutoff value of the price-adjustment cost for each firm charging a relative price of \( p \). All firms that draw an adjustment cost lower than this cutoff will optimally choose to adjust their price. The endogenous adjustment fraction determined by the menu cost of the marginal firm being just equal to the value gained, i.e.,

\[
\xi(\alpha_{jt})w_{0t} = v_{0t} - v_{jt} \tag{11}
\]

In the time dependent case, the fixed cost is either zero or infinite depending on when the firm last changed its price.

Iterating the Euler equation (5) forward, the optimal relative price, \( p^*_t \), can be related to current and expected future variables:

\[
p^*_t = \frac{\sum_{j=0}^{J-1} \beta^j E_t\{ (\omega_{j,t+j}/\omega_{0,t}) \cdot (\lambda_{t+j}/\lambda_t) \cdot \psi_{j,t+j} \cdot \epsilon_{j,t+j} \cdot c_{t+j} \}}{\sum_{j=0}^{J-1} \beta^j E_t\{ (\omega_{j,t+j}/\omega_{0,t}) \cdot (\lambda_{t+j}/\lambda_t) \cdot (\epsilon_{j,t+j} - 1) \cdot (P_{t+j}/P_t) \cdot c_{t+j} \}}, \tag{6}
\]

where \( (\omega_{j,t+j}/\omega_{0,t}) = (1 - \alpha_{jt+j}) \cdot (1 - \alpha_{j-1,t+j-1}) \cdot ... \cdot (1 - \alpha_{1,t+1}) \) is the probability of non-adjustment from \( t \) through \( t + j \), and \( \epsilon_{j,t+j} \) is the elasticity of demand facing a firm with relative output of \( c_{j,t+j}/c_{t+j} \).\(^{12}\) According to (6), the optimal relative price is a fixed markup over real marginal cost (\( p^* = \frac{\xi}{\bar{\epsilon} - 1} \psi \)) if real marginal cost, the demand elasticity, and the price level are expected to be constant over time. More generally, (6) illustrates that the optimal price varies with current and expected future demands, aggregate price levels, real marginal costs, discount factors, the elasticity of demand, and adjustment probabilities. Intuitively, firms know that the price they set today may also apply in future periods, so the expected state of the economy in those future periods affects the price that they choose today. If, for example, marginal cost is expected to be high next period a firm will set a high price in the current period, so as not to sell at a loss next period. Similarly, if the elasticity of demand is expected to be high next period, the firm will not raise its price as much in response to a nominal shock because it will lose a lot of business in the future. The conditional probability terms \( (\omega_{j,t+j}/\omega_{0,t}) \) are present in time-dependent models, but they are not time-varying. In our setup, these conditional probability terms effectively modify the discount factor in a time-varying manner: a high probability of adjustment in some future period leads the firm to set a price that heavily discounts the effects on profits beyond that period.

\(^{11}\) As long as the inflation rate is non-zero and the maximum adjustment cost is finite, there will be a maximum number of periods that any firm will leave its price unchanged. Thus, the state space for this problem is finite.

\(^{12}\) The pricing restriction (6) is a natural generalization of the type derived in time-dependent settings with exogenous adjustment probabilities that are constant through time as in Calvo [1983] (see for example King and Wolman [1996] and Yun [1996]). If the aggregator takes on a constant elasticity of substitution form, then the optimal pricing (in equation (6)) becomes the familiar expression found in Dotsey et. al. (1999).
3.3 The Household

We want to have a household objective function that does not change radically when we consider local labor markets. Therefore, as in Dotsey and King (2001), we assume that there is a super household that chooses consumption and labor for each of its members, so that we avoid the potential complication of differential wealth among individuals that would arise when workers are tied to specific firms. The unified household approach conveniently provides full income insurance. Specifically, the household solves

$$ \max_{c_{jt}, n_{jt}} \left\{ \sum_t \beta^t \sum_j \omega_{jt} \left[ \frac{1}{1 - \sigma} c_{jt}^{1-\sigma} - \frac{\chi}{1 + \phi} n_{jt}^{1+\phi} \right] \right\} $$

subject to:

$$ \sum_j \omega_{jt} c_{jt} \leq \sum_j \omega_{jt} [w_{jt} n_{jt} + z_{jt}], $$

where $c_j$ and $n_j$ are the consumption and labor effort of a household member working for a type j firm; $z_{jt}$ is the profits remitted to the household by a type j firm. In this setting – full insurance and utility that is separable in labor effort and consumption – all households consume the same amount, $c_t$. The first order condition determining labor supply is

$$ w_{jt} = c_t^\phi n_{jt}^\phi, $$

and, hence, $\phi^{-1}$ is Frisch labor supply elasticity.

We further impose the money demand relationship $M_t / P_t = c_t$. Ultimately, the level of nominal aggregate demand is governed by this relationship along with the central bank’s supply of money.

3.4 Monetary Policy and Market Clearing

The model is closed by assuming that nominal money supply growth follows an autoregressive process,

$$ \Delta M_t = \rho \Delta M_{t-1} + m_t, $$

where $m$ is i.i.d. and normally distributed. Depending on the structure of factor markets, equilibrium involves either a wage rate or a vector of wage rates that clear the labor market while simultaneously implying utility maximization and cost minimization. Further, the aggregate price level is such that the money demand equals money supply, and individual firm’s prices are value maximizing.\footnote{There is no barrier to considering alternative monetary policy rules, such as interest rate rules, in our setting. However, we stick with the money supply rule for comparability with the results of other studies.}

13
4 Evaluating predictions about SDP

We now evaluate whether the predictions of the early 1990s literature carry over to our dynamic general equilibrium setting. Throughout this section, we assume that the adjustment cost parameters are such that there is an approximately quadratic hazard function, in a sense made more specific below. In this section, we also restrict attention to the models in which there is a global labor market, so that there is a single real wage $w_t$.

We choose preference parameter values that produce a low elasticity of marginal cost with respect to real output, assuming that $\sigma = 0.25$ and $\phi = 0.05$ implying that the marginal cost elasticity is about .30. Many studies in the early 1990s literature explicitly or implicitly assumed low elasticities of marginal cost with respect to output. For example, in their analyses of real rigidity [1990] and multiple equilibria [1991], Ball and Romer assumed explicitly that utility was linear in consumption ($\sigma = 0$) and that utility was close to linear in work ($\phi$ was small).

4.1 Adjustment timing and the age distribution of prices

The first two predictions comes from Sheshinski-Weiss [1977, 1983]: (i) relatively small menu costs may lead firms to adopt lengthy periods of price inactivity within an inflationary steady-state; and (ii) the shape of the firm’s demand and cost conditions will be important for its frequency of price adjustment.

Figure 2 displays the hazard rates at an annual 4 percent rate of inflation for model I (Dixit-Stiglitz demand) and model II (Kimball kinked demand). To begin, note that the chosen adjustment cost structure indeed leads to steady-state hazard functions that are roughly quadratic in the log relative price deviation, since log $(P_t^*) - \log(P_{t-j}^*) = j \log(\pi)$, where $\pi$ is the steady-state inflation rate. The figure illustrates that the structure of demand and cost has a quantitatively important effect on hazard rates. Firms choose to adjust more frequently if there is a kinked demand curve. The average age of a price in the global DS model is 3.9 quarters and it is 2.2 quarters in the global K model. The expected duration of price fixity is about 8 quarters in the global DS model and it is 4.8 quarters in the global K model.

14 Given that the household efficiency condition is $w_t = c_t^\phi n_t^{1-\phi}$; given that consumption is equal to output; and given that labor is approximately equal to output, the elasticity is approximately $\sigma + \phi$.

15 Additional calibration information is as follows. First, we assume that there is a demand elasticity of 10 at the relative price of 1. With DS demand, this pins down $\varepsilon = -10$. With the K demand, we assume that $\gamma = 1.02$ leading to the demand specification displayed in Figure 1. Choice of adjustment cost parameters is detailed in our working paper, Dotsey and King [2004].

16 Both of the demand models that we study in this section satisfy a condition developed by Sheshinski and Weiss, which is that $p \frac{d^2 x}{dp^2}$ is decreasing in $p$. In their framework, this condition must be imposed if a higher rate of inflation is to increase the frequency of price adjustment.

17 The two features are calculated as follows. First, the average age of price is just $\sum_{j=0}^{J-1} j \cdot \omega_j$, where we adopt a “start of period” age convention. Second, the expected duration of price fixity
The maximum adjustment cost is about 7.5% of production time in both of these economies, which is quite large (we call the fraction of total time devoted to price adjustment $B$ and set it to $B = .015$: since the steady-state fraction of time that individuals devote to market work is $n = .20$, it follows that the adjustment cost is 7.5% of production work). However, because the highest adjustment cost is rarely paid, the average level of adjustment costs is only .42% of production time in model I (global-DS) and it is .86% of production time in model II (global-K), which are much smaller numbers. Another way of thinking about the magnitude of these costs is to measure the resources spent adjusting prices relative to sales, which is sometimes measured in the empirical literature on price adjustment costs: these are .37% and .78%, respectively, for the two economies.

Figure 3 helps us understand why there is more rapid price adjustment in the economy with K-demand than with DS-demand: as a function of the firm’s relative price, profits decline much more sharply when there are deviations of price from the $p = 1$ value that would be optimal in the absence of adjustment costs. The solid and dashed lines in each respective case are the value for all possible prices, while the stars and circles correspond to the prices that are actually chosen by the firm in the steady state.

4.2 Dynamic effects of monetary shocks

In the early 1990s literature on state-dependent pricing, Caplin and Leahy [1991] suggested that there would be strikingly different dynamics with endogenous timing of adjustment, in which the evolving distribution would play a critical role. In this section, we look at the dynamic response of output to an increase in the level of the money stock, which rises on impact by 1% and then gradually increases to 2% above its initial value.\textsuperscript{18}

4.2.1 Model I: SDP dynamics with constant elasticity demand

The tendency for “front-loading” of price adjustments has been a much-discussed feature of sticky price models: if a firm expects the price level to increase in the future and if the firm expects to hold its nominal price fixed for a substantial time, then it will aggressively adjust its price in response to the expected future inflation. In Figure 4, it is clear that front-loading carries over to an SDP environment: the “reset price”, which is the price set by adjusting firms, increases by more than one-for-one

\[ \sum_{j=1}^{\infty} \frac{\alpha_j}{\alpha_0} = \frac{1}{\alpha_0}. \]

In this expression, the probability of a price “surviving” until age $j$ is $\frac{\alpha_j}{\alpha_0} = (1 - \alpha_1)(1 - \alpha_2)\ldots(1 - \alpha_j)$ so that the expression is the sum of the survival probabilities times the additional length of price fixity (1) that derives from each survival. But since the survival probabilities sum to one, there is a particularly simple form of this expression.

\textsuperscript{18}That is, there is a value of $\rho = .5$ in the money supply specification.
with both the money stock and the price level.\footnote{The reset price can increase by substantially more than the price level because only a fraction of the firms are adjusting prices.}

The SDP environment also involves dynamics that are very different from those in time-dependent models of the Taylor-Calvo-Levin form. Notably, there are complicated oscillatory dynamics in the price level, output, labor, marginal cost and inflation. In fact, a fair reaction to these dynamics is that they are very far from any estimates that derive from vector autoregressions or other methods of tracing out empirical responses to monetary changes. But just as with the dynamic responses derived analytically by Caplin-Leahy [1993], which were also far from such empirical estimates, they illustrate that SDP models can deliver dramatically different dynamics for output and other variables than those in standard time-dependent models.

4.2.2 Contrasting TDP with SDP in the DS case

We now contrat the SDP model with a very specific TDP alternative, which we think is a natural benchmark: we use a TDP model that has the exactly same steady-state as the SDP model studied in Figure 4, but we freeze the adjustment rates at their steady-state values Differences between the dynamic responses, reported in Figure ?? then are attributable to whether adjustment rates vary in the face of a monetary shock. Relative to our SDP model, there are larger and more protracted output fluctuations. There is a more sluggish price level, but no oscillatory dynamics.

4.2.3 Model II: SDP Dynamics with Kinked Demand

We next consider the effect of the same monetary shock in a setting with a “smoothed off kinked-demand curve” along the lines suggested by Kimball [1995]: there are very different dynamic responses displayed in Figure 5. Notably, in contrast to the DS model of the last subsection, the reset price is much less responsive under this specification: there is no “front-loading” of price adjustments. There are two very intriguing features. First, the stimulation of real activity lasts for about 10 quarters, but is now followed by a period of real contraction, which lasts for a substantial period but does not undo the effect of the initial stimulation. Second, while the real expansion of economic activity peaks after 4 quarters, the peak effect on inflation occurs much later.

These dynamics are not so evidently at variance with various kinds of macroeconomic evidence.\footnote{Anyone who has estimated vector autoregressions knows that there are many specifications that show monetary disturbances having an initial positive effect on real economic activity and then a negative one (although specification selection means that fewer of these are reported than estimated).} First, in a critique of TDP sticky price models, Mankiw [2001] has argued that any macroeconomic model of the Phillips curve must produce a delayed surge in inflation, that follows an initial real stimulation of economic activity. He uses...
this set of observations to critique standard New Keynesian sticky price models with Calvo price-setting. However, our simple state-dependent pricing model outcomes are reminiscent of Friedman’s [1992] description of the dynamic effects of a change in money growth and they are also broadly consistent with Mankiw’s description. Specifically, in response to a monetary shock Friedman stressed that output responds before inflation. He also suggested that the output response is delayed by about six to nine months and is distributed over time.

In model II, the response of inflation is also distributed over time, but occurs with more of a lag – up to 12 to 18 months. With respect to output, we do not produce the real activity delays that Friedman describes, although output in our model does take two to three quarters before achieving its maximal response. Significantly, however, the response of model inflation is delayed and does not peak until about six quarters.

4.2.4 Contrasting SDP with TDP in the Kinked Demand Case

Looking at the panels of Figure 6, we can again trace a comparison of the SDP and TDP variants. First, the price level increases at about the same rate in the TDP (solid line) and SDP (dashed line) models during the first year, but then it increases more rapidly in the SDP model, leading to a surge in inflation during the second year. (The ‘reset price’ under TDP is marked with a ‘*’, while that under SDP is marked with an ‘o’). Second, the oscillatory dynamics are attributable to changes in the rate of adjustment, since they are not present in the TDP variant.

4.2.5 Understanding the incentives for adjustment

What are the incentives for price adjustment in the dynamic models? At one level, the answer is easy: there is a greater rate of adjustment if there is a greater value to adjusting. However, the determinants of \( v_{t+1} - v_{t+2} \) are complicated, within and across the DS and K-demand models. Accordingly, we start here by focusing directly on a measure of one-period profit, which is revealing about the difference in adjustment incentives. We then discuss aspects of a dynamic decomposition for the K-demand case. Finally, we consider the evolution of the price level once again, displaying the importance of adjustment timing quantitatively.

Contrasting adjustment incentives: a static perspective To begin, we note that a rise in output and an associated increase in marginal cost is an important feature of Figure 5. We therefore start by looking at a measure of the static gain to price adjustment in the face of a 1% rise in real marginal cost, defined as

\[
\frac{z(p^*, \psi) - z(p, \psi)}{z}
\]

where \( z(p, \psi) = pd(p) - \psi d(p) \); \( z(p^*, \psi) \) is the level of profits at the statically optimal price; and \( z = z(1, \psi = \frac{\varepsilon - 1}{\varepsilon}) \) is the level of profit under fully flexible prices.
We begin by graphing this measure as the dashed line in Figure 7 for the K-demand model. First, the price $p^*$ is just above one because the firm faces the rapidly declining profit illustrated in Figure 3 and thus a firm which is free to raise its price will not do so by very much in the face of the increase in marginal cost. Second, given the desirability of a small adjustment, it is intuitive that there is also a small loss of maintaining price $p = 1$, the price that would be optimal in the absence of the rise in marginal cost. Hence, in the kinked demand world, a firm with $p = 1$ also has only a small incentive to pay a fixed cost to adjust its price. However, should its price deviate significantly from $p=1$, then the firm facing a kinked demand has a large incentive to adjust: this was the feature that led to more rapid steady-state adjustment under K-demand in Figure 2 above.

We also find the figure helpful in thinking about why there are larger incentives for price adjustment in response to a rise in marginal cost with DS-demand rather than K-demand: the DS model leads to larger desired price adjustments and therefore larger gains to adjustment near $p=1$. But it leads to relatively smaller effects with large departures from $p = 1$, so that it is also compatible with more extended stickiness in the steady state.

**A dynamic perspective on the adjustment with kinked demand** The adjustment rate for a firm of vintage $j$ is implicitly given by $\xi(\alpha_{jt})w_{0t} = v_{0t} - v_{jt}$. Accordingly, we can take a first order approximation to this expression and deduce that

$$\xi_{\alpha}(\alpha_j)(\alpha_{jt} - \alpha_j) = -\left[\frac{p_j \partial v_{jt}}{w_0} + \log(p_{jt}) - \log(p_j)\right] + \text{other terms}$$

so that it is possible to explore the effects of the price level on adjustment incentives, holding fixed other factors. Specifically, we take the equilibrium solution for $\log(p_{jt}) - \log(p_j)$ and then construct a synthetic series $\tilde{\alpha}_{jt} - \alpha_j$ using the equation above. Given these synthetic series, we can also construct a synthetic series for the vintages, $\tilde{\omega}_{jt} - \omega_j$, which is a dynamic simulation of sorts since it obeys the dynamic equations

$$\tilde{\omega}_{jt} - \omega_j = (1 - \alpha_j)(\tilde{\omega}_{j-1,t-1} - \omega_j) - \omega_{j-1} (\tilde{\alpha}_{jt} - \alpha_j)$$

$$\tilde{\omega}_{0t} - \omega_0 = \sum_{j=0}^{J-1} \left[\alpha_j (\tilde{\omega}_{j-1,t-1} - \omega_j) + \omega_j (\tilde{\alpha}_{jt} - \alpha_j)\right].$$

That is, the synthetic series for $\tilde{\omega}_{jt}$ is constructed solely on the basis of variations in the synthetic adjustment rates $\{\tilde{\alpha}_{jt}\}_{j,t}$, so that it too involves only the effects of $p_{jt}$. We have undertaken this decomposition and have found that effects of $p_{jt}$ are dominant on $\alpha_{jt}$ – in the sense of high $R^2$ – except for those firms which just adjusted, with this exception seeming plausible on the basis of our prior analysis of static profit gain (as illustrated in Figure 7).**That is because the initial price response is so small, there is not much change in $\alpha_{1t}$ do to prices and other factors**
explanes a greater proportion of the change in first bin adjusters] The price effects capture variations in vintage fractions \((\omega_{jt})\) virtually completely.\(^{21}\)

**The evolution of the price level once again** Caballero and Engel [1993] emphasized that the behavior of the price level would be influenced by the interaction of the evolving distribution of prices and the evolving probability that individual price adjustments would take place. To explore this channel within our model, we consider the movement of a linear aggregate of the price level, \(\bar{P}_t = \sum_{j=0}^{J-1} \omega_{jt} P_{jt}\). This price level can be decomposed directly into a part \(\sum_{j=0}^{J-1} \omega_{jt} P_{jt}\) that is the effect of price stickiness when steady-state weights are maintained and an additional component, \(\sum_{j=0}^{J-1} (\omega_{jt} - \omega_{j})P_{jt}\) that derives from the interaction of evolving adjustment rates and past prices. That is, a useful decomposition of the price level suggested by this model is

\[
\bar{P}_t = \sum_{j=0}^{J-1} \omega_{jt} P_{jt} = \sum_{j=0}^{J-1} \omega_{j} P_{jt} + \sum_{j=0}^{J-1} (\omega_{jt} - \omega_{j})P_{jt}
\]

In our framework, we want to calculate a linear decomposition that captures the elements highlighted by (7). To develop such a linear decomposition, we begin by noting that the linear aggregate is related to the perfect (exact, nonlinear) price index (3) according to

\[
\frac{d\bar{P}_t}{\bar{P}_t} = \frac{dP_t}{P_t} + \frac{1}{\sum_{j=0}^{J-1} \omega_{j} P_{jt}} \left\{ \left( \sum_{j=0}^{J-1} \omega_{j} P_{jt} \frac{dp_{jt}}{p_{jt}} + \sum_{j=0}^{J-1} p_{j} d\omega_{j}t \right) \right\}
\]

\[
= \frac{1}{\sum_{j=0}^{J-1} \omega_{j} P_{jt}} \left\{ \left( \sum_{j=0}^{J-1} \omega_{j} P_{jt} \frac{dp_{jt}}{p_{jt}} + \frac{dP_t}{P_t} \right) + \sum_{j=0}^{J-1} p_{j} d\omega_{j}t \right\}.
\]

\(^{21}\)See our working paper, Figures X and Y, for these simulations. The adjustment rate for a firm of vintage \(j\) is implicitly given by \(\xi(\alpha_{jt}) w_{0t} = v_{0t} - v_{jt}\), which we can write as

\[
w_{0t}(\alpha_{jt}) = -z_{jt} + \left( v_{0t} - \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t} v_{0,t+1} \right] \right)
\]

\[
+ \beta E_t \left[ \frac{\lambda_{t+1}}{\lambda_t} \right] (1 - \alpha_{j+1,t+1}) (w_{0,t+1} \xi(\alpha_{j+1,t+1}) + w_{0,t+1} \Xi(\alpha_{j+1,t+1}))
\]

Accordingly, it is more generally possible to link variations in adjustment rates to three factors: profits \((z_{jt})\); a measure of the urgency of adjustment \((v_{0t} - \beta E_t \frac{\lambda_{t+1}}{\lambda_t} v_{0,t+1})\); and an "option value" of adjustment term that involves future adjustment costs. Further, the effects of profitability can be decomposed into consequences of relative price variations; marginal cost variations; and aggregate demand variations. We have undertaken some exploration of the analytics and quantitative performance of such measures in our model, but these experiments are not reported in the working paper because of the dominance of the effect of the price level on relative prices.
i.e., as the sum of a term that captures the effect of nominal price adjustments at fixed weights and a term that captures the effects of changes in adjustment probabilities. Applying this decomposition to the K-demand model, we produce Figure 8.

The top panel of this Figure shows that the exact price level (3) and the linear aggregator are indistinguishable to the eye in this economy, but that there is an important difference between these and the fixed hazard part of the price level, which is 
\[
\frac{1}{\sum_{j=0}^{J-1} \omega_j p_j} \left\{ \sum_{j=0}^{J-1} \omega_j p_j \left( \frac{dp_j}{P_j} + \frac{dP_j}{P_j} \right) \right\}.
\]
Interestingly, this difference is miniscule during the first few quarters after the monetary shock hits, but it becomes important later on, rising with inflation, as the second panel shows. The background to this panel is Figure 2, which shows that 22% of the firms in the economy are adjusting each period in steady-state. The second panel of Figure shows that this fraction rises by about 3% during the second year after the shock, which is when inflation peaks (adjustment rates here are measured as a deviation from the steady-state level).

On the basis of this analysis, we conclude that this case has strong effects of the type identified by Caballero and Engel [1993]: the interaction of the nearly quadratic hazard, sticky nominal prices, and the price level is at the heart of understanding the dynamics of inflation. Concretely, the delayed response in inflation shown in Figure 5 arises because there is initially little movement in the price level, so that firms have little incentive to pay to adjust prices. However, as the price level continues to rise, more firms have this incentive and their collective action produces a further rise in the price level which additionally reinforces the extent of adjustment.

### 4.3 Multiplicity and nonexistence

Ball and Romer [1991] highlight the possibility of multiple equilibria in basic SDP models, stressing that changes in the price level can alter the privately optimal pattern of price adjustment for firms. In our DSGE model, we have found that there apparently is a substantial part of the parameter space in which there are both multiplicity and nonexistence according to the criteria of Blanchard and Kahn [1980]. That we find these regions in the K-demand case is perhaps not too surprising, given the central role that the price level played in triggering adjustment in the prior section.

In Figure 9, for the K-demand model, we calculate the number of stable eigenvalues of the dynamic model at each point in a grid of the adjustment cost parameter $B$ – which is the largest value that the adjustment cost can be – and the labor utility parameter $\phi$. If there is a ‘*’ in the Figure, then this means that there is a unique, stable rational expectations solution: the number of stable eigenvalues is equal to the number of predetermined variables. Since we are studying $B = .015$ and $\phi = .05$ in the Figures above, we start by noting that there is a ‘*’ in that location. We also note that there is a region around this point in which there is uniqueness, but that it is close to the border with a region of nonexistence. At other points in the figure, there are fewer stable eigenvalues than predetermined variables, which implies nonexistence according to Blanchard-Khan, so that we put an ‘o’ in that location. Finally, there
are points in which there are more stable eigenvalues than predetermined variables, which implies multiplicity (nonuniqueness) according to Blanchard-Khan, so that we put a '◊' in that location. John and Wolman [2004] have begun the important work of exploring the conditions under which dynamic multiple equilibria occur in SDP models, together with providing economic interpretation about these findings. Their analysis suggests that this is a complex and subtle topic.

It is important to stress that nonexistence and nonuniqueness do not always arise. For one example, if we were to produce a version of this figure for the comparable TDP model, then all points would be a unique equilibrium: this buttresses the Ball-Romer idea that multiplicity is related to state dependence. For another, a version of this figure for the DS model examined above (demand elasticity =10) would also lead to uniqueness for all parameter values in this grid. Finally, in exploring both K and DS models with a global labor market, a higher elasticity of marginal cost to output (over one) and the adjustment cost distribution similar to that used in DKW [1999], we also did not find nonexistence or nonuniqueness. But in some investigations, nonexistence and nonuniqueness can arise for precisely the parameter values that interest a researcher. For example, we would like to look at adjustment cost specifications with a smaller value of $B$ than $B = .015$, so as to reduce the extent of steady-state stickiness. But we cannot, because this moves us out of the region of solvability. Moreover, in exploring SDP model dynamics in the current investigation, we have encountered – particularly in models with local factor markets – many cases in which there are apparently multiple equilibria or there is nonexistence. In our experience, Figure 9 is representative in that it suggests that there is indeed a complicated relationship, since the relevant regions are discontinuous.

5 Specific factors and persistence

An important line of macroeconomic research has explored the implications of the various sticky-price model features for the timepaths of real and nominal variables, with one particular topic being the persistence of real effects in the wake of Chari, Kehoe and McGrattan [2000]. Work by Kimball [1995] and Rotemberg [1996] viewed each firm as having a pool of workers to draw from as opposed to buying labor in a competitive market. Hence, even if the firm purchased labor competitively, it knew that an increase (decrease) in its demand would raise (lower) the wage rate and it would take this factor into account in pricing its product. The intuition behind this result is as follows. An increase in the current price cuts demand, which lowers marginal cost when factors are specific. In turn, the lower marginal cost makes it efficient to price less aggressively. For this reason, Kimball [1995] and Rotemberg [1996] suggested that there would be increased price sluggishness and persistence if one switches from a global to local view of factor markets. They also discuss the fact that in setting a low price, the firm must balance the fact that there will be high demand in the future and that this output must be produced at high cost, but they
conclude that the overall effect is to make firms price less aggressively and to increase price level sluggishness.

We use different parameter values to explore this idea. First, we assume that there is a higher elasticity of marginal cost with respect to output and in particular that it is about 1.5 (we do this by assuming \( \sigma = 1 \) and \( \phi = .5 \)). Second, since Kimball and Rotemberg both used Calvo-like models, we assume that there is an adjustment cost structure that makes the global-DS version into an “approximate Calvo” model within the steady-state, having an adjustment hazard of about .2 for eight quarters before complete adjustment occurs.\(^22\)

### 5.1 The promise

We begin by illustrating the promise of the specific factors mechanism, calculating the output impulse responses for an approximate Calvo model and displaying it in Figure ??.

The dramatic promise of specific factors appears in the output responses for models I-IV, with specific factors alone (model III) producing virtually the same persistence as the variable elasticity of demand specification (II).\(^23\) The combination of the two New Keynesian mechanisms, as originally suggested by Kimball, yields a great deal of persistence.

### 5.2 Approximate Calvo

We want to explore the effects of state dependence within a battery of models that have an approximate Calvo form, i.e., a steady-state hazard that is roughly constant for a number of periods. Accordingly, we select the parameters of our cost function so that there is a flat hazard for the DS-global setting for 8 quarters, which is a “truncated Calvo” steady state. The necessary cost function, \( \xi(\alpha) \), is one that is fairly flat until \( \alpha = .2 \) then rises very sharply to close to the maximum cost. Faced with this adjustment cost, firms with a range of different values of \((v_0 - v_j)/w_0\) will all choose \( \alpha = .2 \). When \((v_0 - v_j)/w_0 \geq B = .015\), then all firms will choose to adjust \( \alpha = 1 \).

With this cost structure in hand, we can explore the effect of changing the structure of demand and the effect of localizing factors on hazard rates and vintage fractions, as we did previously for the alternative cost specification. Figure ?? displays the results, revealing some worth highlighting. First, as suggested above, the figure

\(^{22}\) We also choose these parameter values – more in line with values used in the real business cycle literature such as King, Plosser and Rebelo [1988] – because there is no endogenous persistence in this case, as emphasized by Chari, Kehoe and McGrattan [2000]. Hence, any increase in persistence will be attributable to specific factors. The choice also allows us to evaluate whether, as is sometimes suggested, local factor markets substitute for a low marginal cost elasticity in generating persistence.

\(^{23}\) In his conference comments, Susanto Basu stressed the symmetry of specific factors and variable demand elasticity under Calvo pricing. Thus, our parametric specification – although not designed for this purpose – corresponds to essentially equivalent strength of these two mechanisms.
displays “approximate Calvo” form of adjustment: the optimal hazard is about .2 if it is not one. Second, in the global factor market setting, as above, the shift from DS-demand to K-demand lowers the number of periods over which there is incomplete adjustment by firms, cutting it from 8 in the DS case to 4 in the K-demand case. Third, for both of the local market cases, the results are dramatic: moving from global to local markets cuts the interval of partial adjustment to just one period. To understand this, we return to the original intuition from Kimball [1995] and Rotemberg [1996]: with a fixed hazard, a firm sets its price relatively less aggressively than under global markets because it wants to take advantage of low current marginal cost, which occurs when price is raised above the benchmark value of one. In doing so, as discussed above, it must balance the fact that there will be high demand in the future and that this output must be produced at high cost. But these future periods of low profits – resulting from high demand and high cost occurring together – can be avoided through a payment of an adjustment cost, so that the firm makes aggressive use of this option in both local market settings. In fact, under our the current parameterization, it keeps prices fixed for only two periods (including the initial period of price adjustment).

This dramatic implication of very short intervals of price fixity for the DS-local and K-local models could be altered by assuming larger values of the maximum price adjustment cost (which is here set equal to .015). But, then, the conclusion would be that models with local factor markets require substantially higher adjustment costs to obtain a specified pattern of “near Calvo” adjustment. In fact, in order to produce price fixity of four periods in the DS case we must ramp up adjustment costs so that 5.85% of labor effort is devoted to price changes at a cost of 5.5% of sales. Thus, a TDP pricing model with local labor markets and four vintages of firms is ignoring tremendous incentives that firms have for adjusting their price. This level of menu costs strikes us as implausible.

5.3 Consequences of endogenous adjustment

To explore the implications of moving from global to local (specific) factor markets, we now explore how the dynamics are altered as this feature of the model is altered, holding the cost of adjustment structure discussed above. Figure 10 displays the effect of moving from a global to local market under state-dependent pricing with the DS-demand structure, which indicates that the persistence gain suggested by Figure ?? turns into a persistence loss under state-dependent pricing. Figure 13 displays the effect of moving from a global to local market under state-dependent pricing with the K-demand structure, which indicates that the persistence gain suggested by Figure ?? also turns into a persistence loss under state-dependent pricing.

Looking across this pair of figures, it is clear that there is more persistence with model IV (K-local) than with model III (DS-local). However, more importantly, this pair of figures illustrates a principal: economic mechanisms that have one set of
consequences under time-dependent pricing (as in Figures ?? and ??) can have a very
different set of consequences under state-dependent pricing (as in Figure 10 and 13)
because the mechanisms alter the incentives that agents have to adjust the timing of
their price changes.

5.4 The effect of K-demand on dynamics once again

It is important to stress that persistence is not necessarily reduced when a model
feature lowers the number of periods of price-fixity in the steady-state. As back-
ground, Figure ?? shows that the number of periods of price-fixity is roughly halved
when DS-demand is replaced by K-demand. Figure ?? shows the effects of moving
from DS-demand to K-demand on the dynamic response to a monetary shock (in
this diagram, a solid line refers to the K-demand model and a dashed line refers to
the DS model). Despite the smaller number of price vintages, the K-demand model
continues to have the important implication discussed above: the K-demand makes
firms less aggressive on the pricing front, converting the more than 2% change in the
reset price on impact to about a .8% change in the reset price on impact. That is,
even though the current framework is one with a higher elasticity of marginal cost to
output and a different structure of adjustment costs, the price level still is initially
more sluggish than under DS-demand, which brings about both a larger real output
response and a more persistent one.

In terms of the dynamics of the inflation rate, the K-demand model also leads to
a peak inflation rate that lags the output peak, although it does so only by one or
two quarters in this case. However, the change in the adjustment cost function from
one involving a nearly quadratic hazard to one involving a nearly constant hazard
does mean that there is a quite different decomposition of the sources of variations
in the price level. If we were to reproduce Figure 8 for the current adjustment cost
structure, then we would find that there was only a miniscule difference between the
various price level measures and a very small change in the fraction of firms altering
the timing of their price adjustment in the face of the monetary shock.

6 Summary and conclusions

What are the implications of state-dependent pricing models for dynamic macroeco-
nomic modeling?. In this paper, we showed that these are rich and varied, working
within a battery of quantitative dynamic general equilibrium models.

We began by investigating whether some of the results of the 1990s literature on
state-dependent pricing carried over to our models, which are constructed along the
lines proposed by Dotsey, King and Wolman [1999]. This earlier literature reached
the general conclusion that SDP models were very different from the more commonly
employed time-dependent pricing models (TDP models). More specifically, it sug-
gested the following ideas: (1) the steady-state pattern of price adjustment depends
importantly on the nature of the demand and cost functions of the firm; (2) the dynamic effect of money on output within state-dependent pricing models is dramatically different from that in time-dependent models, possibly involving complicated cyclical adjustment processes and nonlinear responses; (3) the evolution of the price level is substantially affected by the adjustment strategies of firms interacting with heterogenous prices; and (4) multiple equilibria can readily arise in state-dependent pricing models, due to complementarities in price-setting, even with the type of exogenous money stock rule that nearly always guarantees a unique equilibrium in a time-dependent models. Working with assumptions characteristic of that literature, specifically that there is a low elasticity of marginal cost with respect to output and that there is a hazard function which rises quadratically in a measure of price gaps, we found support for all of these ideas, except that our use of linear approximation methods precluded studying nonlinear dynamics. Exploring the dynamic response of output and inflation to monetary shocks in a model with a “smoothed off kinked demand curve”, we unexpectedly found a pattern of output and inflation dynamics that has been suggested to be inconsistent with sticky price models: with the output peaking after four quarters, and inflation peaking nearly a year later.

In evaluating the implications of state-dependent pricing for dynamic macroeconomic models, we also considered issues related to ongoing research into model features that can lead to larger persistence of output responses to monetary shocks. Working with an adjustment cost structure that was designed to produce a relatively flat hazard function over eight quarters in the reference case of a constant elasticity demand curve and a global labor market, we found that two model modifications – a variable demand elasticity and a local labor market – led to sharply reduced intervals of stickiness. The kinked demand curve model had a flat hazard over 4 quarters rather than 8; the local labor market models had only one period of incomplete price adjustment. For this reason, it turned out that the local labor market friction lowered persistence under SDP rather than raising persistence as it does under TDP. However, the result for the kinked demand curve was that there was larger persistence (relative to constant elasticity demand) even though the steady-state duration of price fixity was smaller under kinked rather than constant elasticity demand. Taken together, these examples show that state-dependent pricing may alter the conclusions that a researcher would draw about the effect of structural elements of a model.

In closing their 1989 discussion of state-dependent pricing and time-dependent pricing, Blanchard and Fischer considered the types of economic exchanges that might be best modeled using either approach, but they could only summarize a few empirical studies about price adjustment dynamics (notably Cecchetti [1986] and Kashyap [1995]). Recent work by Bils and Klenow [2003] and Klenow and Krystov [2003]

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24 See Willis [2003] for an interesting modern reworking of Cecchetti’s analysis of magazine prices.
25 See Wolman [2003] for a comprehensive survey and critical appraisal of a variety of evidence on duration of price fixity and the magnitude of price adjustment costs.
is providing valuable new information about the behavior of consumer goods prices in the U.S., both in terms of the timing and magnitude of adjustments, and many studies are underway for other countries.\textsuperscript{26} It is clear from this ongoing work that the average duration of price fixity differs substantially across industries and that there are important period-to-period changes in the fractions of goods whose prices are changed. It is also clear that aspects of this work raise challenges for existing models of price adjustment, both time-dependent and state-dependent. Learning further about the general implications of these pricing models for macroeconomic dynamics, as we have here, will be a central component of the important project of taking SDP models to data.

\textsuperscript{26}http\url{http://www.european-central-bank.org}, notably the cooperative project being sponsored by the European Central Bank.
References


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