Lumpy Investment and State-Dependent Pricing in General Equilibrium*

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Abstract

What are the aggregate consequences of microeconomic lumpy decisions? This is by now a classical question. Most existing general equilibrium analyses focus, however, on one single decision at a time. In the present paper we analyze simultaneous (S,s) pricing and investment decisions. Surprisingly, equilibrium dynamics are similar to what they would be in the absence of restrictions on price or capital adjustment. In that sense we generalize the prominent irrelevance result by Thomas (2002).

Keywords: Lumpy Investment, Sticky Prices.

JEL Classification: E22, E31, E32

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1 Introduction

Many microeconomic decisions are lumpy in nature. Caballero and Engel (2007) note that examples include not only infrequent price adjustment by firms but also investment decisions, durable purchases, hiring and firing decisions, inventory accumulation, and many other economic variables of interest. Recently, some important progress has been made in understanding the consequences of microeconomic lumpiness for aggregate dynamics (See, e.g., Dotsey et al. 1999, Thomas 2002). It is, however, striking to note that most existing theoretical analyses of (S,s) decisions have focused on *one* particular lumpy decision at a time. This motivates our paper. We try to understand the macroeconomic consequences of *simultaneous* lumpy decisions in general equilibrium. To this end we study macroeconomic consequences of state-dependent pricing *and* lumpy investment. We obtain two main results. First, the restriction on capital adjustment does not have quantitatively important implications for equilibrium dynamics. Second, the same is true for the restriction on price adjustment. Our first finding generalizes a prominent result by Thomas (2002). She observes that (S,s) lumpy and frictionless investment imply similar dynamics for aggregate quantities in the context of a standard technology-driven RBC model. Interestingly, we confirm her equivalence result in a framework featuring sticky prices combined with monopolistic competition. The second result is in the spirit of Golosov and Lucas (2007). They show that (S,s) price stickiness has small aggregate consequences in the presence of (ad hoc) idiosyncratic productivity shocks. We demonstrate that endogenous changes in firm-level productivity resulting from (S,s) lumpy investment can micro-found this.

What is the relevance of our results? We show that the dynamic consequences of simultaneous (S,s) decisions differ crucially from what they are if it is assumed that investment and pricing decisions are made according to time-dependent adjustment rules. The latter assumption is pursued in Sveen and Weinke (2007). In that paper we obtain equivalence between a time-dependent monetary lumpy investment model and a specification featuring a convex capital adjustment cost at the firm-level. Specifically, monetary disturbances are found to have large real consequences in a way which is empirically plausible. In the present paper we obtain a diametrically opposed result which is due to the (S,s) nature of the decisions under consideration. Of course, there is no agreement in the literature on which way of modeling lumpy decisions is most appealing (See, e.g., Woodford 2008). Our results suggest, however, that this is one of the most important questions in monetary economics.

So far very little work has been done on the aggregate consequences of simultaneous lumpy decisions at the microeconomic level. The paper which is most closely related to ours is the recent work by Johnston (2007). Like our paper he also analyzes simultaneous (S,s) pricing and investment decisions at the firm level. An important difference with respect to our work lies, however, in the way in which the heterogeneity among firms is reduced in order to make the problem tractable. In that regard our assumptions are more general, as we are going to see.[1] Johnston concludes that the Thomas (2002) result regarding dynamic consequences of technology shocks is overturned in the presence of a price-setting decision at the firm level, whereas we confirm her result. On the other hand, Johnston also finds that the presence of an (S,s) investment decision results in a reduction of the real consequences of monetary disturbances and, like us, he relates that to the above mentioned result by Golosov and Lucas (2007).

The remainder of the paper is organizes as follows. Section 2 outlines the model. Section 3 presents the results and Section 4 concludes.

[1] Another important difference with respect to our model lies in the specification of monetary policy. He assumes a stationary process for the growth rate of real balances (combined with an interest rate inelastic demand for real balances), whereas we assume that monetary policy takes the form of an interest rate rule.

2 The Model

2.1 Households

There is a continuum of households and they are assumed to have access to a complete set of finacial markets. Each household has the following period utility function

$$U\left(C_t, L_t\right) = \ln C_t + \eta \ln\left(1 - L_t\right),$$

which is separable in its two arguments C_t and L_t. The former denotes a Dixit-Stiglitz consumption aggregate while the latter is meant to indicate hours worked. Our notation reflects that a household's time endowment is normalized to one per period and throughout the analysis the subscript t is used to indicate that a variable is dated as of that period. Parameters η is a scaling parameter whose role will be discussed below. Specifically, the consumption aggregate reads

$$C_t \equiv \left(\int_0^1 C_t\left(i\right)^{\frac{\varepsilon-1}{\varepsilon}} di\right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{1}$$

where ε is the elasticity of substitution between different varieties of goods $C_t\left(i\right)$. The associated price index is defined as follows

$$P_t \equiv \left(\int_0^1 P_t\left(i\right)^{1-\varepsilon} di\right)^{\frac{1}{1-\varepsilon}}, \tag{2}$$

where $P_t\left(i\right)$ is the price of good i. Requiring optimal allocation of any spending on the available goods implies that consumption expenditure can be written as $P_t C_t$.

Households are assumed to maximize expected discounted utility

$$E_t \sum_{k=0}^{\infty} \beta^k U\left(C_{t+k}, L_{t+k}\right),$$

where β is the subjective discount factor. The maximizations is subject to a sequence of budget constraints of the form

$$P_t C_t + E_t \{Q_{t,t+1} D_{t+1}\} \leq D_t + P_t W_t H_t L_t + T_t, \tag{3}$$

where $Q_{t,t+1}$ denotes the stochastic discount factor for random nominal payments and D_{t+1} gives the nominal payoff associated with the portfolio held at the end of period t. We have also used the notation W_t for the real wage and T_t is nominal dividend income resulting from ownership of firms.

The labor supply equation implied by this structure takes the standard form

$$\frac{\phi C_t}{1 - N_t} = W_t, \tag{4}$$

and the consumer Euler equation is give by

$$Q_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-1} \left(\frac{P_{t+1}}{P_t} \right)^{-1}. \tag{5}$$

We also note that $E_t \{Q_{t,t+1}\} = R_t^{-1}$, where R_t is the gross risk free nominal interest rate.

2.2 Firms

There is a continuum of firms and each of them is the monopolistically competitive producer of a differentiated good. Each firm $i \in [0, 1]$ is assumed to maximize its market value subject to constraints implied by the demand for its good and the production technology it has access to. Moreover each firm faces random fixed costs of price and capital adjustment. This implies generalized (S, s) rules for price-setting and for investment. Productivity shocks and monetary policy shocks represent the sources of aggregate uncertainty. In each period the time line is as follows.

1. The cost of adjusting the price, c_p, realizes.

2. The firm changes its price (or not).

3. Production takes place.

4. The cost of adjusting the capital stock, c_k, realizes.

5. The firm invests (or not).

Let us now be more specific about the above mentioned constraints. Each firm i has access to the following Cobb-Douglas production function

$$Y_t(i) = Z_t L_t(i)^{1-\alpha} K_t(i)^{\alpha} - \phi, \tag{6}$$

where α denotes the capital share in production and the parameter ϕ is ment to indicate fixed cost of production. The aggregate level of technology, Z_t, is assumed to be given by the following process

$$\ln Z_t \equiv z_t = \rho_z z_{t-1} + e_{z,t}, \tag{7}$$

where $e_{z,t}$ is i.i.d.

In order to invest or change it's price the firm must pay a fixed cost. More precily, we denote the cost function for investment and price setting as $C_{p,t}(i)$ and $C_{k,t}(i)$. They are both meassured in units of the aggregate good and are given by

$$C_{k,t}\left(K_t(i), K_{t+1}(i), c_k\right) = \begin{cases} \mu K_t(i) \text{ if } K_{t+1}(i) = (1-\delta) K_t(i), \\ K_{t+1}(i) - (1-\delta-\mu) K_t(i) + c_k \text{ otherwise,} \end{cases} \tag{8}$$

$$C_{p,t}\left(P_t(i), P_{t+1}(i), c_p\right) = \begin{cases} 0 \text{ if } P_{t+1}(i) = P_t(i), \\ c_p \text{ otherwise,} \end{cases} . \tag{9}$$

where δ is the rate of depresiation net of maintenance, μ. We assume symmetric triangular density functions for c_k and follow Dotsey et al (1999) and Bakhshi (2007) and let the density function for c_p be given by

$$G_p(c_p) = c_1 + c_2 \tan(c_3 c_p - c_4),$$

where c_1, c_2, c_3, and c_4 are constants.

Cost-minimization on the part of households and firms implies that demand for good i is given by

$$Y_t^d(i) = \left(\frac{P_t(i)}{P_t}\right)^{-\epsilon} Y_t^d, \tag{10}$$

where aggregate demand is $Y_t^d = C_t + I_t + C_{p,t}$, which consists of consumption, aggregate investment, $I_t \equiv \int_0^1 C_{k,t}(i)\,di$, and aggregate price-setting costs, $C_{p,t} = \int_0^1 C_{p,t}(i)\,di$.

Each firm maximizes its market value

$$E_t \sum_{k=0}^{\infty} Q_{t,t+k} \left\{\Phi_{t+k}(i) - C_{k,t+k}(i) - C_{p,t+k}(i)\right\}, \tag{11}$$

where $\Phi_t(i) \equiv P_t(i)\,Y_t(i) - W_t L(i)$ is the gross operating profit. The maximization is done subject to the constraints in equations (6), (8), (9), and (10).

We now give a recursive characterization of a firm's problem. It is convenient to split the Bellman equation into two parts:

$$\widetilde{V}(K_t(i), P_{t+1}(i)) = E_{c_k} \max_{K_{t+1}(i)} \left\{Q\; V(K_{t+1}(i), P_{t+1}(i)) - C_k(i)\right\}, \tag{12}$$

$$V(K_t(i), P_t(i)) = E_{cp} \max_{P_{t+1}(i)} \left\{\Phi_t(i) - C_p(i) + \widetilde{V}(K_t(i), P_{t+1}(i))\right\}, \tag{13}$$

where $V(K_t(i), P_t(i))$ is the value function at the beginning of the period, before c_p realizes. $\widetilde{V}(K_t(i), P_{t+1}(i))$ is the value function after production, before c_k realizes.

2.3 Market Clearing and Monetary Policy

The goods market clearing condition reads

$$Y_t(i) = Y_t^d(i) \text{ for all } i. \tag{14}$$

Clearing of the labor market requires

$$\int_0^1 L_t(i)\,di = L_t. \tag{15}$$

Last, we follow Walsh (2005) and let monetary policy take the form of a simple interest rate rule

$$R_t = R_{t-1}^{\phi_r}\left(\beta^{-1}\left(\frac{P_t}{P_{t-1}}\right)^{\phi_\pi}\right)^{1-\phi_r} e^{e_{r,t}}, \tag{16}$$

where parameters ϕ_π and ϕ_r measure the responsiveness of the nominal interest rate in response to changes in current inflation and past nominal interest rates, respectively, and $e_{r,t}$ is i.i.d.

2.4 Computational Strategy

Let $k(i) \equiv K(i)/K$ and $p(i) \equiv P(i)/P$ denote firm i's relative to average capital stock and price. We choose a two-dimensional discrete rectangular grid in $\log k$ and $\log p$, centered (roughly) around the average values of those variables.[2] The distance between grid points in k-direction equals $m\log(1-\delta)$ for some integer m, such that a firm which does not adjust its capital stock just moves m steps down the grid. The grid in p is not a multiple of the inflation rate. If a firm that starts at a point of the grid and does not adjust its price, then it moves down the grid by the equivalent of the inflation rate, and would therefore end up inbetween grid points. To stay on the discrete grid, we approximate this situation by assuming that the price jumps stochastically to one of the two neighboring grid points, such that the expected price does not change.

Solving for the steady state is a two-dimensional fixed point problem in aggregate demand Y and wage rate W. Given a guess of Y and W, we solve the firm's problem by the following iterative procedure

[2] We center the grid around the frictionless steady state values of $\log k$ and $\log p$. Obviously, this is only "roughly" equal to their average values in our baseline model.

1. Assume we have a guess of the firm value function $V(k,p)$. The firm then maximizes its value, defined as current period profits plus the discounted continuation value $V(k,p)$. Then we compute optimal choices, *conditional on adjusting*, as follows. In the second part of each period, the firm chooses next period's k. Choices are discrete, restricted to the points on the discrete grid. Since adjustment costs are independent of adjustment size, the optimal capital is only a function of the price set by the firm, not its current k. This k enters into next period's production.

In the first part of each period, the firm chooses the price at which it sells its product in that same period. We first find the optimal p on the discrete grid; assume it is the i-th point p_i. Then we assume the firm chooses the price continuously in the range (p_{i-1}, p_{i+1}). Call the optimal price p^*, which is a function of firm capital k, and will in general not be on the discrete grid. For the profit maximization, we assume that the firm sells at p^* this period, but next period the price jumps stochastically to neighbouring grid points, so as to leave the expected price unchanged. Given optimal choices, the adjustment probabilities are a function of the distribution of the adjustment costs.

2. Given a firm policy (i.e., optimal choices of k and p), we can compute a new guess of the value function $V(k,p)$ under the assumption that the policy is played forever. This is just a linear equation system in V. Iterate steps 1. and 2. until convergence; this is a standard iteration in policy space, for which convergence can be proven.

Given equilibrium adjustment probabilities, we can compute the ergodic distribution of k and p, and see whether they are consistent with the guesses of Y and W. We solve for equilibrum Y and w by a quasi-Newton method.

Having computed the steady state, we compute the dynamics, assuming (infinitesimally) small shocks. We can restrict attention to the ergodic set of (k,p)-points in the steady state. With our choices for the dynamics of k and p, infinitesimally small shocks would not move the economy away from the ergodic set. Assume the ergodic set is given by n points $x_1, \ldots, x_n$, where each x is a (k,p)-pair from the grid. The state of the economy at each point in time is then given by the following variables:

$$\begin{aligned} &V(x_i), \qquad i = 1, \ldots, n \\ &\Phi(x_i), \qquad i = 1, \ldots, n \\ &z \end{aligned}$$

where $\Phi(x_i)$ is the mass of firms at point x_i, and z is the vector of exogenous shocks. Then stack all the state variables plus aggregate jump variables of interest into the vector Θ_t. Denote by Θ^* the vector of those variables in the stationary state. Then compute an approximation of the dynamics of Θ_t about the steady state Θ^*. This approximation is linear in the aggregate shocks and in Θ_t itself.

2.5 Baseline Calibration

We require that the steady state of our model is empirically plausible. The discount factor β is set to 0.99, which implies a steady state real interest rate of about 4 per cent. Steady state inflation is set to 0.005, i.e. about a 2 per cent anual growht rate of consumer prices. Parameter η is set to imply that those households spend one-third of their available time working. We follow Golosov and Lucas (2003) in assuming $\epsilon = 7$, which implies a desired frictionless markup of about 20%. Technology is parametrized such that our model implies a labor share of 0.64 and a yearly capital-to-labor ratio of 2.352 (see, e.g., Khan and Thomas 2008). This implies that $\alpha = 0.3398$ and $\phi = 0.0139$.[3] We set the rate of depreciation (gross of maintenance) to be $\delta + \mu = 0.025$ which implies a steady state investment to capital ratio of 10% a year. As in Bachman et al (2007) we allow for 50% maintenance, i.e. we set μ to 0.0125. The parameters in the CDF's for the fixed costs of price setting and investment[4]

[3] Parameters α and ϕ are choosen such that the frictionless counterpart of our model implies a labor share of 0.64 and a capital-to-output ratio of 2. 353. This implies that in our baseline model the corresponding values are 0.6335 and 2.3245.

[4] We let the width of the distribution be $\pm 50\%$ arround an expected value of 0.0015.

are chosen to be consistent with the following micro evidence. Each quarter 25% of firms change their nominal price (Aucremanne and Dhyne 2004, Baudry et al 2004, and Nakamura and Steinsson 2008). Each year about 18% of firms make infrequent investments ($I/K > 20\%$), and the total investment of those firms make up 50% of total investment (see, e.g., Khan and Thomas 2008).[5]. Last, in calibrating the exogenous driving forces of our model we use standard values from the literature. As Walsh (2005) we use $\phi_r = 0.9$ and $\phi_\pi = 1.1$. Finally, the autocorrelation in the technology process, ρ_z, is set to 0.95 (see, e.g., Erceg, Henderson and Levin 2000 and Walsh 2005).

3 Results

3.1 Steady State

Our ultimate goal is to understand aggregate consequences of simultaneous (S,s) pricing and investment decisions. To this end it is useful to start by analyzing how the *interaction* of those decisions affects the stochastic steady state of our model. To illustrate this, we start by computing the ergodic set under the baseline calibration.

[Figure 1 about here]

The last figure shows that there is substantial heterogeneity in relative prices and capital holdings in the ergodic set. In order to better understand the nature

[5] We choose the value 0.002 for the mode of the triangular distribution, with lower and upper bounds of 0.001 and 0.003. As far as the S-shaped distribution we follow Bakhshi et al (2007) and let $c_3 = 438.4$ and $c_4 = 1.26$. The upper bound B of the cost is set to 0.00475, and these choices pin down c_1 and c_2.

$$\begin{aligned} c_2 &= \frac{1}{\tan\left(c_3 B - c_4\right) - \tan\left(-c_4\right)}; \\ c_1 &= -c_2 \ \tan\left(-c_4\right). \end{aligned}$$

The above choice implies an average frequency of spikes of 5.2 per cent, and that lumpy investors make up 48.1 per cent of total investment. In addition average price setting frequency is 26.5 per cent.

of the interaction between pricing and investment decisions it is useful to restrict attention to the price-setters. This is shown in the upper panel of figure 2.

[Figure 2 about here]

For high enough capital stocks a clear pattern emerges. The higher the capital stock the smaller the chosen relative price. For small enough capital stocks that relationship becomes hump-shaped. The reason is simple. Price-setters take rationally into account that they are likely to increase their capital holdings before they will re-optimize their prices. This limits the incentive to post a high relative price. The distribution of investors can be understood in an analogous way. The lower panel of figure 2 shows that for large enough relative prices the chosen capital stock depends inversely on the price in place. For small enough relative prices, however, that relationship becomes backward bending. The intuition is that investors anticipate that they are likely to to increase their prices by the time when the chosen capital becomes productive. This limits the incentive to choose a high capital stock.

It is also instructive to consider the adjustment hazard for price-setting and for investment. The hazard is defined as the probability that adjustment takes place conditional on the time elapsed since the last adjustment. This is illustrated in figure 3.

[Figure 3 about here]

Interestingly, the price hazard is not monotonically increasing. Nakamura and Steinsson (2007) find that a downward-sloping price hazard is empirically plausible. None of the sticky price models which have been proposed in the literature is consistent with that empirical finding. We therefore regard it as an interesting feature of our model that the price hazard function is at least decreasing over some intervals. The economic reason behind this result is that price-setters are likely to invest at some point in the future. Conditional on a lumpy increase in its capital stock a firm has little incentive to change its price. In fact, a low relative price resulting from an old nominal price might be tailor made in the presence of a high capital stock.

3.2 Equilibrium Dynamics with Lumpy Investment and State-Dependent Pricing

We now use our model to analyze dynamic consequences of economic shocks. Our first result regards technology shocks. This is illustrated in figure 4.

[Figure 4 about here]

The last figure shows impulse responses to a one standard deviation shock to aggregate technology. To put these results into perspective we compare the impulse responses under our baseline calibration to a benchmark case in which capital is much more flexible.

[Figure 5 about here]

Figure 5 shows that there are only minor differences with respect to the former case which substantiates our earlier claim that the Thomas (2002) result turns out to be robust in the context of our model.

Next, we analyze dynamic consequences of a one hundred basis points shock to the interest rate rule. The results are shown in figure 6.

[Figure 6 about here]

Interestingly, we do not find persistent dynamic consequences of monetary policy shocks for real economic variables. This is highlighted in figure 6. Endogenous changes in technology resulting from lumpy investment therefore imply a result in the spirit of Golosov and Lucas (2007).[6] Again, we compare the results under our baseline calibration to the ones which obtain in the presence of a much smaller degree of lumpiness in investment.

[Figure 7 about here]

The striking similarity between the last two cases is another manifestation of the Thomas (2002) result. But frictionless capital accumulation generally implies

[6] Interestingly, Dotsey and King (2005) also find that firm-specific factors reduce price stickiness in an (S,s) pricing model which abstracts from capital accumulation.

extremely large real effects of monetary disturbaces on impact. It is therefore not surprising that the impact responses of the real variables in the last figure differ from their counterparts in a flexible price model.

4 Conclusion

We propose a generalized (S,s) pricing and investment model and find that neither friction has quantitatively important consequences for aggregate quantities in general equilibrium. This is an important generalization of the irrelevance results by Thomas (2002) and Kahn and Thomas (2008). Specifically, our result shows that an (S,s) investment decision destroys the ability of an otherwise standard (S,s) pricing model to imply persistent real consequences of monetary policy shocks.

It remains, however, to be seen whether time-dependent or state-dependent modeling of lumpy decisions is most appealing. A recent contribution to that debate is Woodford (2008). He argues forcefully that it is not clear at all that (S,s) modeling is better micro-founded than time-dependent modeling. Our results in the present paper show that the relevance of this question is increased dramatically if the interaction between lumpy decisions is taken into account. Clearly, following up on those issues will be at center stage on our research agenda.

References

Aucremanne, Luc, and Emmanuel Dhyne (2004), “How Frequently Do Prices Change? Evidence based on the micro data underlying the Belgian CPI”, European Central Bank Working Paper No. 331.

Bachmann, Ruediger, Ricardo J. Caballero, and Eduardo R.M.A. Engel (2006), “Lumpy Investment in Dynamic General Equilibrium”, NBER Working Paper 12336.

Bakhshi, H., H. Khan, B. Rudolf (2007), “The Phillips Curve under State-Dependent Pricing”, *Journal of Monetary Economics* 54, 2321-2345.

Baudry, L., H. Le Bihan, P. Sevestre, and S. Tarrieu (2004), “Price Rigidity. Evidence from the French CPI Micro-Data”, European Central Bank Working Paper No. 384.

Caballero, Ricardo J., and Eduardo R.M.A. Engel (2007), “Price Stickiness in Ss Models: New Interpretations of Old Results”, Journal of Monetary Economics 54, 100–121.

Cooper, Russell W., and John C. Haltiwanger (2006), “On the Nature of Capital Adjustment Costs”, *Review of Economic Studies* 73, 611–633.

Dotsey, Michael, and Robert G. King (2005), “Implications of State-Dependent Pricing for Dynamic Macroeconomic Models”, *Journal of Monetary Economics* 52, 213-242.

Dotsey, Michael, Robert G. King, and Alexander L. Wolman (1999), “State-Dependent Pricing and the General Equilibrium Dynamics of Money and Output”, The Quarterly Journal of Economics 114, 655-690.

Dotsey, Michael, Robert G. King, and Alexander L. Wolman (2006), “Inflation and Real Activity with Firm-Level Productivity Shocks: A Quantitative Framework”, mimeo.

Erceg, Christopher J. , Dale W. Henderson, and Andrew T. Levin (2000), “Optimal monetary policy with staggered wage and price contracts”, *Journal of Monetary Economics* 46, 281-313.

Golosov, Mikhail, and Robert E. Lucas Jr.(2007), “Menu Costs and Phillips Curves”, *Journal of Political Economy* 115, 171-199.

Johnston, Michael K. (2007), “Real and Nominal Frictions within the Firm: How Lumpy Investment Matters for Price Adjustment”, mimeo.

Khan, Aubhik, and Julia K. Thomas (2008), “Idiosyncratic Shocks and the Role of Noncenvixities in Plant and Aggregate Investment Dynamics”, *Econometrica* 76, 395-436.

Nakamura, Emi, and Jon Steinsson (2008), “Five Facts About Prices: A Reevaluation of Menu Cost Models”, forthcoming *The Quarterly Journal of Economics.*

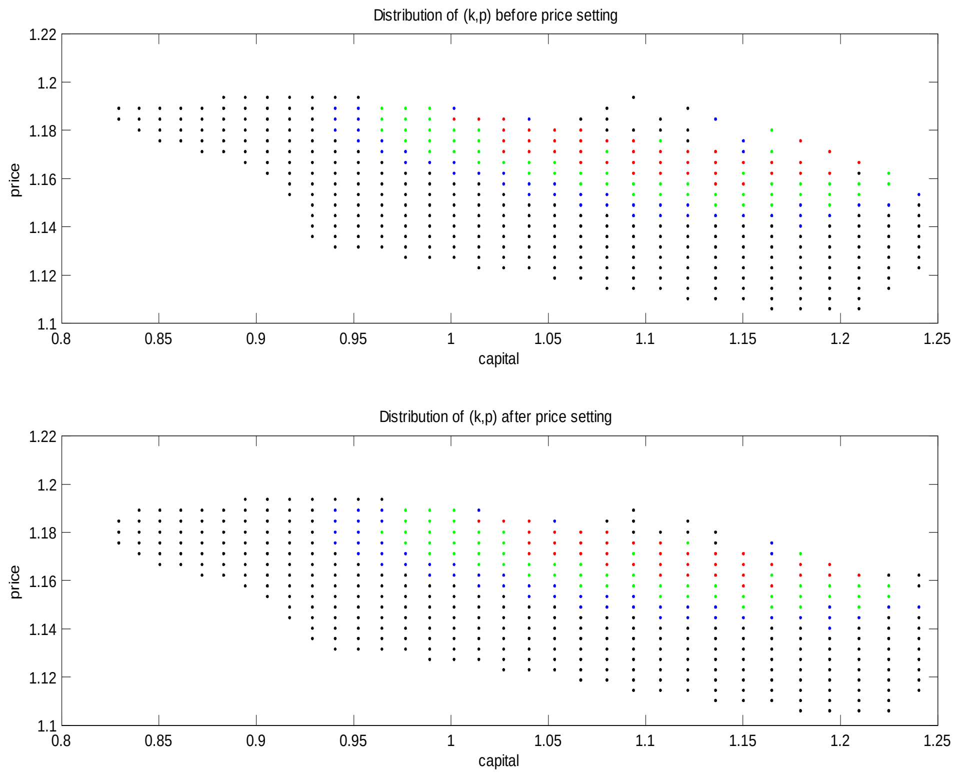
Sveen, Tommy, and Lutz Weinke (2007), “Lumpy Investment, Sticky Prices, and the Monetary Transmission Mechanism”, *Journal of Monetary Economics* 54, 23-36.

Thomas, Julia K. (2002), “Is Lumpy Investment Relevant for the Business Cycle?”, *Journal of Political Economy* 110(3), 508-534.

Walsh, Carl E. (2005), “Labor Market Search, Sticky Prices, and Interest Rate Policies”, *Review of Economic Dynamics* 8, 829-849.

Woodford, Michael (2003), Interest and Prices: Foundations of a Theory of Monetary Policy, Princeton University Press.

Woodford, Michael (2008), “Information-Constrained State-Dependent Pricing”, mimeo.



Distribution of (k,p) before price setting
price
capital
Distribution of (k,p) after price setting
price
capital

Figure 1

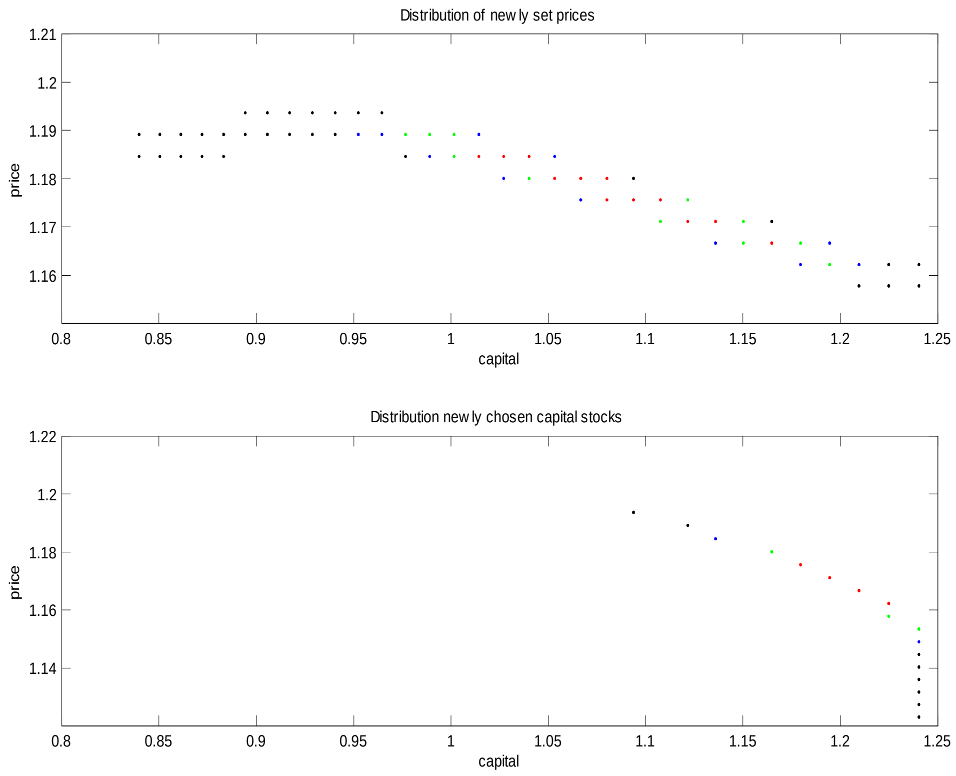

Distribution of newly set prices
price
capital
1.21
1.2
1.19
1.18
1.17
1.16
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
1.25
Distribution newly chosen capital stocks
price
capital
1.22
1.2
1.18
1.16
1.14

Figure 2

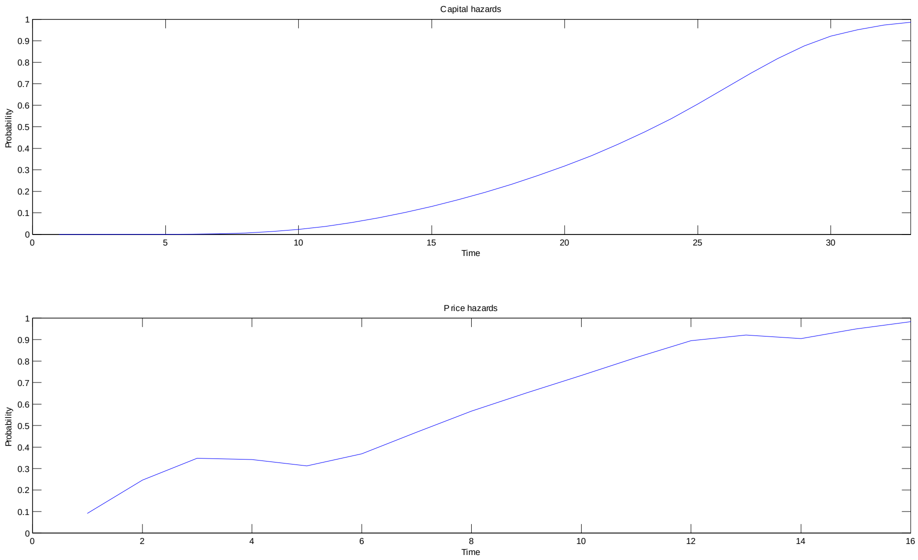

Capital hazards
Probability
Time
Price hazards
Probability
Time

Figure 3

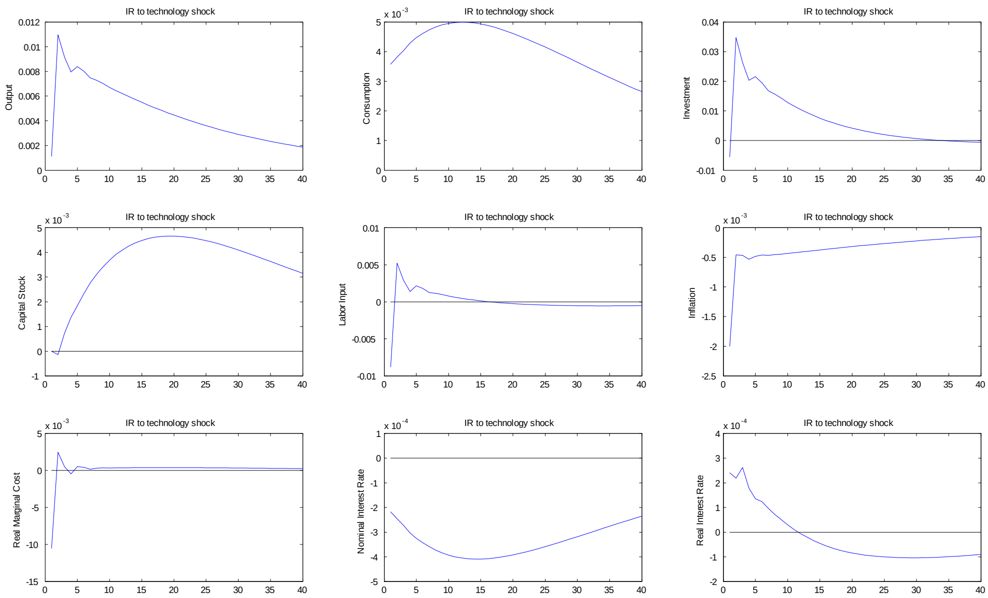

IR to technology shock
Output
IR to technology shock
Consumption
IR to technology shock
Investment
IR to technology shock
Capital Stock
IR to technology shock
Labor Input
IR to technology shock
Inflation
IR to technology shock
Real Marginal Cost
IR to technology shock
Nominal Interest Rate
IR to technology shock
Real Interest Rate

Figure 4

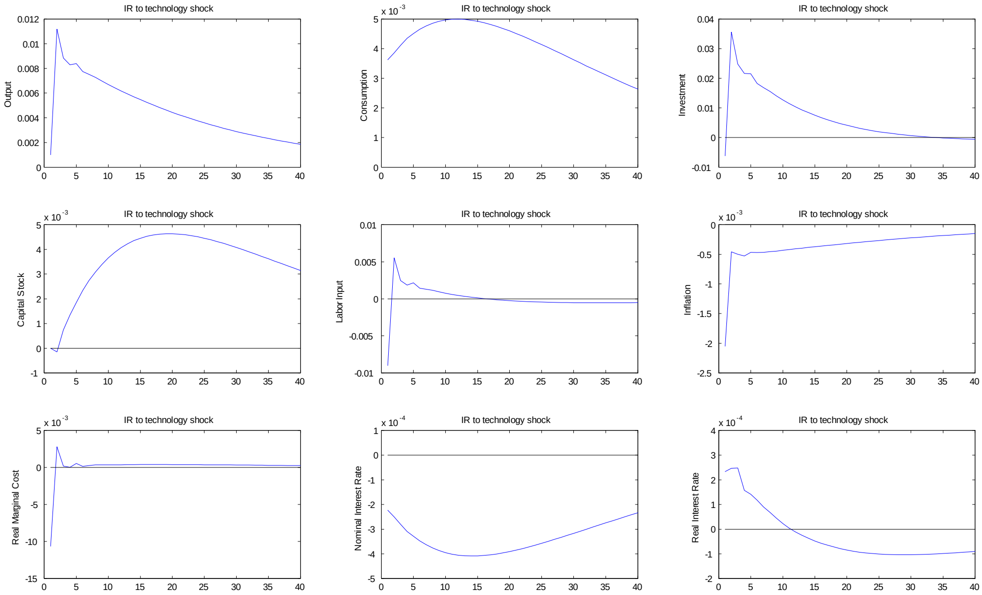
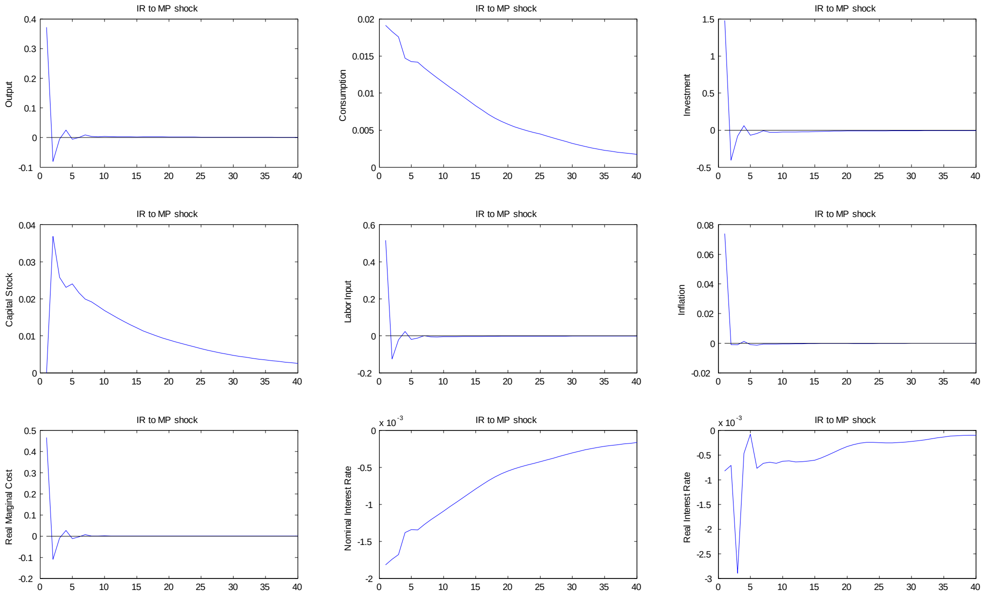
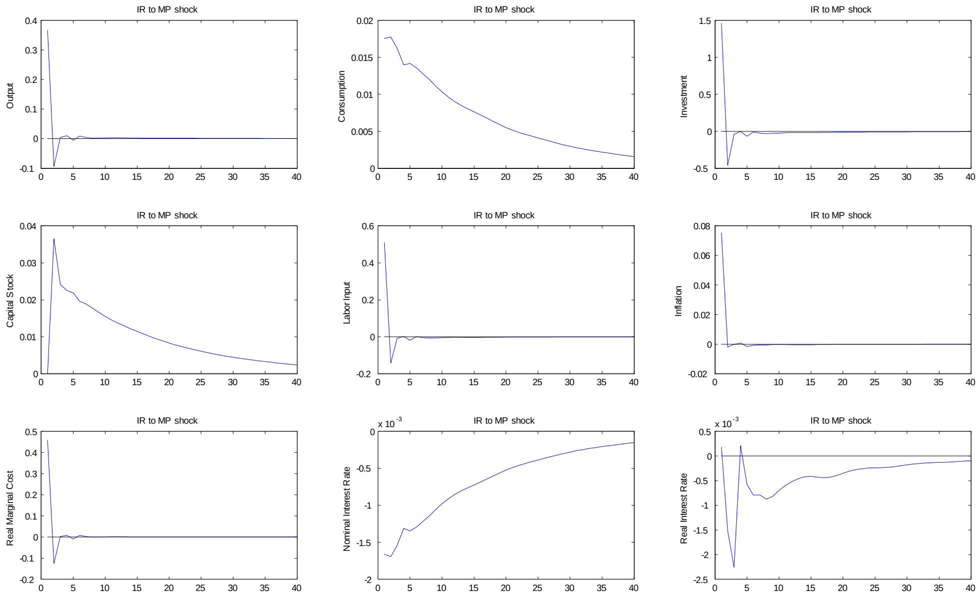

IR to technology shock
Output
Consumption
Investment
Capital Stock
Labor Input
Inflation
Real Marginal Cost
Nominal Interest Rate
Real Interest Rate

Figure 5



IR to MP shock
Output
IR to MP shock
Consumption
IR to MP shock
Investment
IR to MP shock
Capital Stock
IR to MP shock
Labor Input
IR to MP shock
Inflation
IR to MP shock
Real Marginal Cost
IR to MP shock
Nominal Interest Rate
IR to MP shock
Real Interest Rate

Figure 6


IR to MP shock
Output
Consumption
Investment
Capital Stock
Labor Input
Inflation
Real Marginal Cost
Nominal Interest Rate
Real Interest Rate
x 10^-3