

Relative Price Fluctuations in a Multi-Sector Model with Imperfect Competition*

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Abstract

Countercyclical fluctuations in the price of investment in consumption units are often attributed to investment-specific technology shocks. This paper examines two alternative sources for such fluctuations: sector-specific markup variations, and cross-sectoral differences in the intensity of materials usage. Procyclical competition and the higher variability of investment relative to consumption decreases the relative price of investment during expansions. Secondly, greater use of intermediate inputs, which amplifies productivity shocks, in investment-producing sectors has a similar effect. Empirically, I find that each of these two mechanisms accounts for about one-sixth of the observed fluctuations in the price of investment.

JEL codes: E32, D43.

Keywords: relative price of investment; firm entry and exit; endogenous markups; multi-sector modeling.

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1 Introduction

Sector-specific productivity shocks have become a standard feature in technology driven models of the business cycle at least since a seminal work by Greenwood et al. (2000) Greenwood et al. (2000) on the subject. Studies have focused on investment-specific shocks to explain the negative correlation between investment and its relative price (in terms of consumption goods) that is observed in U.S. data, the idea being that a positive shock on productivity in the investment sector pushes up output in that sector while pushing down its relative price. A number of authors have concluded that these shocks play a quantitatively important role in shaping the business cycle: Greenwood et al. (2000) argues that one-third of output fluctuations is due to such shocks, while Fisher (2006), Justiniano and Primiceri (2008) and Justiniano et al. (Forthcoming) find that their contribution is more than half; Schmitt-Grohé and Uribe (2008), on the other hand, come to the conclusion that investment shocks play a negligible role.

The present paper examines two alternative sources of counter-cyclical fluctuations in the price of investment, namely movements in sector-specific price markups and secondly, sectoral differences in materials (intermediate inputs) usage.

Research (see Rotemberg and Woodford, 1999 and Bloch and Olive, 2001) indicates that competition among firms increases during booms which results in a fall in output prices relative to factor prices, making for countercyclical markups. Given that investment is more variable than consumption over the business cycle, markups will be more variable in the former sector. It therefore follows that during a boom, the price of investment in terms of consumption goods will fall, leading to a negative correlation between investment and its relative price. While others have examined the effect of a long-run decline in such markups (see for example Ramey, 1996), the present paper focuses on the short-run implications of these fluctuations.

A well-known problem for many RBC models which feature countercyclical movements in the price of investment is their inability to replicate the high degree of comovement in sectoral output observed in the data. However, Hornstein and Praschnik (1997) and Horvath (2000) show that by taking into account the pervasive use of materials in the U.S. economy, one can generate an amount of sectoral comovement which is broadly in line with the data. Boldrin et al. (2001) has shown that by introducing habit formation

in consumption improves the results. Lastly, Monacelli (2009), introduced borrowing constraints in a New Keynesian model and examined the effects of a monetary shock.

As pointed out, another source of volatility in the price of investment, is materials usage by sector. Specifically, sectors that use materials intensively are less affected by increases in factor prices (wages and interest rates) during upswings, making for a situation in which the relative prices of their goods will decrease. As the investment goods-producing sector is more intermediate-goods intensive, it follows that this will lead to countercyclical movements in the price of investment.

To formalize this, the monopolistic competition framework found in Gali and Zilibotti (1995) is adopted, in which each industry is composed of an endogenous number of establishments paying a fixed operating cost and operating under Cournot competition. A positive productivity shock will then result in the entry of new establishments, leading to an increase in competitive pressure and thus a fall in markups. This is similar to Jaimovich and Floetotto (2008) except for the fact that in this model markups are sector-specific.

Empirically, I proceed in two stages. In the first, I choose an identification strategy that directly infers markup-induced movements in the price of investment from sectoral quarterly data on the number of establishments (reference). Using the equilibrium conditions of the model outlined above, one can derive an expression for the price of investment which depends exclusively on the number of establishments in each sector and on model parameters. In a second stage, the model is simulated, in order to establish whether the recovered fluctuations in the price of investment are consistent with the model's simulated moments. Inferring price movements directly from data on the number of establishments and comparing the results with simulated moments allows us to check whether the simplified modeling of entry and exit has implications which are consistent with the data. Both methods show that sector-specific markups account for approximately one-sixth of the volatility in the price of investment. Sectoral differences in materials usage intensity account for another one-sixth, which combined account for one-third of the volatility.

The findings are consistent with Schmitt-Grohé and Uribe (Forthcoming) who show that total factor productivity and the relative price of investment are cointegrated, and that a common stochastic trend in neutral and investment-specific productivity can account for three-fourths of the variance

in the growth rate of output. This model, however, only considers temporary shocks; permanent shocks would have permanent effects on the price of investment, by lowering markups, and because of the mentioned materials usage asymmetry; both effects would lead to the cointegration relation mentioned above. This raises the possibility that the fluctuations which Schmitt-Grohé and Uribe (Forthcoming) attribute to a common stochastic trend are, in fact, due to purely neutral shocks.

Dos Santos Ferreira and Lloyd-Braga (2005) show that in models with counter-cyclical market power, indeterminacy and multiplicity of steady-states may arise in the presence of market power. In order to keep the paper simple, I focus on local approximations around stable steady-states, thereby disregarding the above issue.

The paper is organized as follows: section 2 presents the model; section 3 deals with its calibration; section 4 infers the movements in the price of investment from sectoral establishment data; section 5 looks at the implications of the simulated model; and section 6 discusses the results and concludes the paper.

2 A Multi-Sector Model with Endogenous Markups

The economy consists of a finite number of sectors; each sector contains a measure one of sub-sectors. As in Gali and Zilibotti (1995), within each sub-sector, a homogeneous good is produced by an endogenous number of establishments that pay a fixed operating cost and compete à la Cournot. Sectoral output is made by combining sub-sectoral goods; consumption and investment are produced by combining sectoral goods. The sectoral modelization framework is similar to Ngai and Samaniego (2009), and the only source of uncertainty in the model is a neutral productivity shock. Time is discrete, and time subscripts are omitted when possible.

Preferences are represented by

$$U = E_0 \sum_{t=0}^{\infty} \beta^t [\log(C_t) + \kappa \log(N_t - L_t)], \quad (1)$$

where L_t denotes hours worked at time t , N_t denotes the endowment of hours, and β is the discount factor, with $\beta \in (0, 1)$.

2.1 Technology

Sectors are indexed by $x \in \{1, 2, \dots, N\}$, sub-sectors by $m \in (0, 1)$, and establishments in each sub-sector by $n \in \{1, 2, \dots, N_{xm}\}$.

Consumption and investment are produced under perfect competition using a range of sectoral goods as inputs. The outputs of the representative firm producing consumption and investment goods are

$$C = \prod_x C_x^{\zeta_{xC}} \quad (2)$$

and

$$I = \prod_x I_x^{\zeta_{xI}}, \quad (3)$$

where C_x (I_x) is the part of aggregate output in sector x which is used to make consumption (investment) goods. Both sectors operate under constant returns to scale, so that $\sum_x \zeta_{xC} = \sum_x \zeta_{xI} = 1$.

Establishments producing final output in each sector x also operate under perfect competition and use sub-sectoral goods Y_{xm} as inputs. The output of the representative firm in each sector x is given by the constant elasticity of substitution function

$$Y_x = \left(\int_0^1 Y_{xm}^{\frac{\sigma-1}{\sigma}} dm \right)^{\frac{\sigma}{\sigma-1}}, \quad (4)$$

where σ corresponds to the elasticity of substitution between any two intermediate goods, with $\sigma > 1$.

Finally, firm n producing sub-sectoral good m uses capital K_{xmn} , labor L_{xmn} and materials M_{ixmn} from each sector i as inputs. Each firm's constant returns to scale production technology is

$$Y_{xmn} = AK_{xmn}^{\alpha_x} L_{xmn}^{\theta_x} \prod_i M_{ixmn}^{\gamma_{ix}}, \quad (5)$$

where $\alpha_x + \theta_x + \sum_i \gamma_{ix} = 1$. $A_t = \exp(a_t) (1 + \gamma_a)^t$ is aggregate productivity, with $\gamma_a \geq 0$ its growth rate and a_t a covariance stationary shock:

$$a_t = \varphi a_{t-1} + \varepsilon_t, \quad \varepsilon_t \sim N(0, \sigma_\varepsilon^2), \quad (6)$$

with $0 < \varphi < 1$. Since all establishments within a sub-sector produce a homogeneous good, total output in sub-sector m is simply the sum of each firm's production:

$$Y_{xm} = \sum_n Y_{xmn}.$$

The total amount of materials used by sub-sector xm is

$$M_{ixm} = \sum_n M_{ixmn}.$$

Establishments within each sub-sector compete à la Cournot. The number of establishments in each industry is determined under free entry. In order to operate, each establishment needs to pay a fixed operating cost of ϕ_x in terms of its own production; this cost is sector-specific and grows at the average growth rate of sectoral output.

Sectoral output Y_x is used for producing consumption and investment goods, as an input in each sub-sector, and for covering fixed costs:

$$Y_x \geq C_x + I_x + \sum_i \sum_m M_{xim} + \phi_x \int_0^1 N_{xm} dm. \quad (7)$$

Capital and labor are homogeneous and can be freely reallocated across sectors, industries and establishments at any point in time. Aggregating across establishments n , sub-sectors m and sectors x yields the following resource constraint for aggregate capital:

$$K \geq \sum_x K_x, \quad (8)$$

where $K_x = \int_0^1 \left(\sum_{n=1}^{N_{xm}} K_{xmn} \right) dm$ is the total capital stock used by sector x . Similarly, the resource constraint for labor is

$$L \geq \sum_x L_x, \quad (9)$$

where $L_x = \int_0^1 \left(\sum_{n=1}^{N_{xm}} L_{xmn} \right) dm$. The law of motion for K_t is

$$K_{t+1} = (1 - \delta) K_t + I_t, \quad (10)$$

where δ stands for the physical depreciation rate of capital.

2.2 Competitive Equilibrium

The representative agent maximizes his utility (1) subject to his budget constraint

$$(1 + r_t) K_t P_{I,t} + w_t L_t - K_{t+1} P_{I,t} - C_t P_{C,t} \geq 0,$$

where r and w stand for the rental rates of capital and labor, while P_C and P_I denote the price of consumption and investment. The first order conditions with respect to K_t and L_t are

$$\frac{P_{I,t}}{C_t} = \beta E_t \left[(1 + r_{t+1}) \frac{P_{I,t+1}}{C_{t+1}} \right], \quad (11)$$

$$\frac{w_t}{C_t} = \frac{\kappa}{(N_t - L_t)}. \quad (12)$$

The representative firm producing consumption and investment goods maximizes

$$\pi_C^* = \max_{\{C_x\}_{x=1}^N} C \cdot P_C - \sum_x C_x P_x$$

and

$$\pi_I^* = \max_{\{I_x\}_{x=1}^N} I \cdot P_I - \sum_x I_x P_x,$$

where P_x is the price of sectoral good x . The first-order conditions for the choice of inputs C_x and I_x are

$$P_x = \zeta_{xC} \frac{C}{C_x} P_C \quad (13)$$

and

$$P_x = \zeta_{xI} \frac{I}{I_x} P_I. \quad (14)$$

In each sector x , the representative firm chooses its inputs $\{Y_{xm}\}_{m=0}^1$ to maximize its profits π_x given sub-sectoral goods prices P_{xm} :

$$\pi_x^* = \max_{\{Y_{xm}\}_{m=0}^1} \left[\left(\int_0^1 Y_{xm}^{\frac{\sigma-1}{\sigma}} dm \right)^{\frac{\sigma}{\sigma-1}} P_x - \int_0^1 Y_{xm} P_{xm} dm \right]. \quad (15)$$

The first order condition for Y_{xm} yields the usual demand function for each intermediate good m in sector x :

$$P_{xm} = \left(\frac{Y_x}{Y_{xm}} \right)^{1/\sigma} P_x. \quad (16)$$

As pointed out, establishments within each sub-sector xm compete à la Cournot. A given firm n producing the intermediate good Y_{xmn} chooses its inputs K_{xmn} and L_{xmn} and M_{ixmn} to maximize profits, taking as given other establishments' decisions:

$$\pi_{xmn}^* = \max_{K_{xmn}, L_{xmn}, \{M_{ixmn}\}_{i=1}^N} \left[Y_{xmn} P_{xm} - (r + \delta) P_I K_{xmn} - w L_{xmn} - \sum_i M_{ixmn} P_i - \phi_x \right], \quad (17)$$

where P_{xm} is given by the demand for good Y_{xm} in equation (16). The first order conditions for K_{xmn} and L_{xmn} satisfy

$$P_I (r + \delta) = \left(1 - \frac{Y_{xmn}}{\sigma Y_{xm}} \right) \alpha_x \frac{Y_{xmn}}{K_{xmn}} P_{xm}, \quad (18)$$

$$w = \left(1 - \frac{Y_{xmn}}{\sigma Y_{xm}} \right) \theta_x \frac{Y_{xmn}}{L_{xmn}} P_{xm}, \quad (19)$$

while materials inputs from each sector satisfy

$$P_x = \left(1 - \frac{Y_{xmn}}{\sigma Y_{xm}} \right) \gamma_{ix} \frac{Y_{xmn}}{M_{ixmn}} P_{xmn}. \quad (20)$$

Considering only symmetric equilibria in which the number of establishments is the same in all the sub-sectors of a given sector, and integrating over all sub-sectors, yields the factor price equations for each sector x :

$$P_I (r + \delta) = \left(1 - \frac{1}{\sigma N_x} \right) \alpha_x \frac{Y_x}{K_x} P_x, \quad (21)$$

$$w = \left(1 - \frac{1}{\sigma N_x} \right) \theta_x \frac{Y_x}{L_x} P_x, \quad (22)$$

and

$$P_i = \left(1 - \frac{1}{\sigma N_x} \right) \gamma_{ix} \frac{Y_x}{M_{ix}} P_x \quad (23)$$

for $i = \{1, 2, \dots, N\}$. M_{ix} is the total use of good i as an input in sector x . Aggregating (5) across sub-sectors and establishments, one can also obtain gross production in each sector:

$$Y_x = A K_x^{\alpha_x} L_x^{\theta_x} \prod_i M_{ix}^{\gamma_{ix}}. \quad (24)$$

The equilibrium conditions differ from those found for a standard neo-classical growth model in that there is a wedge

$$\mu_x = \frac{1}{\sigma N_x} \quad (25)$$

between the price of an input and its marginal productivity. This wedge disappears as N_x , the number of establishments, goes to infinity. The ratio of price over marginal cost is given by $\frac{1}{1-\mu_x}$; however, for simplicity, I will refer to μ_x as the markup for sector x .

Under free entry, the number of establishments in each sector adjusts at each point in time to ensure that profits, which are given by equation (17), are zero in all sectors:

$$\pi_{xmn}^* = 0, \forall x, m, n. \quad (26)$$

Ignoring integer constraints for the number of establishments and aggregating equation (26) over all intermediate goods yields the aggregate zero profit condition for each sector:

$$Y_x \mu_x = \phi_x N_x, \quad (27)$$

which implies that the expected profits obtained from charging a price which is higher than marginal cost (left-hand side) are equal to the total operating costs which are incurred (right-hand side).

Using the above expression to substitute for N_x in equation (25) then yields the markup as a function output:

$$\mu_x = \sqrt{\frac{\phi_x}{\sigma Y_x}}. \quad (28)$$

One can show that in a two-sector model in which output in the first (second) sector, labeled C (I), is used exclusively to make consumption (investment) goods, the price of investment in consumption units satisfies:

$$\frac{P_I}{P_C} = \left[\frac{(1 - \mu_C)^{\gamma_{CC} + \gamma_{IC}}}{(1 - \mu_I)^{\gamma_{CI} + \gamma_{II}}} [(r + \delta) P_I]^{\alpha_I - \alpha_C} w^{\theta_I - \theta_C} \cdot \Theta \right]^{\frac{1}{\gamma_{CI} + \gamma_{IC}}},$$

where Θ is a constant which depends on technology parameters (see appendix A). If the model is symmetric, i.e., if technology parameters are the same in

both sectors:

$$\begin{aligned}\gamma_{CC} &= \gamma_{CI}, \\ \gamma_{IC} &= \gamma_{II}, \\ \alpha_C &= \alpha_I, \\ \theta_C &= \theta_I,\end{aligned}$$

the price of investment becomes

$$\frac{P_I}{P_C} = \frac{1 - \mu_C}{1 - \mu_I} = \left(1 - \sqrt{\frac{\phi_C}{\sigma Y_C}}\right) / \left(1 - \sqrt{\frac{\phi_I}{\sigma Y_I}}\right). \quad (29)$$

In this case, all movements in the relative price of investment are due to sector-specific markup fluctuations; markups in each sector depend negatively on sectoral output. In the presence of comovement between the production of consumption and investment goods, fluctuations in μ_I will dominate as long as investment is more volatile than consumption, leading to a countercyclical movement in the price of investment.

In the case of perfect competition the price of investment is (with P_C normalized to one):

$$P_I = \left[(r + \delta)^{\alpha_I - \alpha_C} w^{\theta_I - \theta_C} \cdot \Theta\right]^{\frac{1}{\gamma_{CI} + \gamma_{IC} + \alpha_C - \alpha_I}}.$$

During an expansion, the interest rate r and wages w will increase; sectors which are heavier users of materials will be more affected by this, and the price of their output will increase relative to other sectors' prices. As I will show, sectors which mainly produce investment goods use a greater proportion of materials. In the simplified two-sector model, this implies either $\alpha_I < \alpha_C$, $\theta_I < \theta_C$, or both. Hence, asymmetry in materials usage is another source of counter-cyclicity in the price of investment. The effect is weakened and could even be reversed if the capital share of income is much larger in the investment sector, i.e., if $\alpha_I > \gamma_{CI} + \gamma_{IC} + \alpha_C$. However, it turns out that the capital share of income is actually smaller than average in sectors which mainly produce investment goods.

Notice that the shock to productivity ε is neutral in the sense that it affects all sectors' productivity in the same way; however, it does affect the relative price of sectoral goods in the case of 'asymmetric' (in the sense described above) economies.

An equilibrium for this model is defined as a sequence

$$\{X_t\}_{t=0}^{\infty} \text{ for } X = \{C, I, C_x, I_x, K_x, L_x, M_{xi}, A, P_x, N_x, w, r\} \quad \forall x, i$$

which satisfies the first order conditions for the households' problem (11) and (12) and for the production of consumption and investment goods (13) and (14), $N \cdot (N + 2)$ factor price equations (21 through 23), the law of motions for capital (10) and for aggregate productivity (6), the resource constraints for sectoral output (7), capital (8), and labor (9), and the expression for the number of establishments in each sector (27) and markups (28); the price of good 1 is normalized to one. The model is normalized, and simulated using Dynare (see Collard and Juillard, 2001).

3 Calibration

The parameters that need to be determined are the discount rate β , the capital depreciation rate δ , the steady-state growth rate of aggregate output per capita, γ_Y , the parameter determining the elasticity of substitution between intermediary goods σ , the variance of the neutral shock σ_ε , and the vectors of technology parameters

$$\begin{aligned} \alpha &= [\alpha_1 \quad \cdots \quad \alpha_N], \\ \theta &= [\theta_1 \quad \cdots \quad \theta_N], \\ \gamma &= \begin{bmatrix} \gamma_{11} & \cdots & \gamma_{1N} \\ \vdots & \ddots & \vdots \\ \gamma_{N1} & \cdots & \gamma_{NN} \end{bmatrix}, \\ \zeta_C &= [\zeta_{1C} \quad \cdots \quad \zeta_{NC}], \\ \zeta_I &= [\zeta_{1I} \quad \cdots \quad \zeta_{NI}], \end{aligned}$$

and

$$\phi = [\phi_1 \quad \cdots \quad \phi_N].$$

Quarterly data on the number of establishments is available for 13 sectors covering the entire private non-farm economy. In order to fully utilize this data set, the model is calibrated to match those same 13 sectors, where N is the number of sectors. The sample period is 1992:3-2009:3, which corresponds to the years for which sectoral establishment data is available; The length of a period is set to one quarter.

Table 1: Parameterization

Parameter	Value	Parameter	Value
β	99%	κ	1.79
δ	1.96%	φ	95%
γ_Y	0.58%		

The growth rate of output γ_Y , the depreciation rate δ , and the standard error of the productivity shock σ_ε , are set to match the following average quarterly values for aggregate U.S. data: a real growth rate of output per capita of .58%; a quarterly depreciation rate of 1.96%; and an output volatility of 1.44%. κ is set such that the average fraction of time spent working is one-third; the discount factor β is set to .99; and φ , the parameter governing the persistence of technology shocks, is set to .95.

Given that σ and ϕ_x always appear together in the equilibrium equations, they cannot and need not be estimated separately. Instead, the relevant variable for calibration is the markup over gross production, which is equal to

$$\Phi_x = \frac{Y_x}{Y_x - \phi_x N_x} - 1 = \frac{\mu_x}{1 - \mu_x}.$$

Jaimovich and Floetotto (2008) find that estimates in the literature for this markup range between 5% and 15%. Given an absence of reliable data on the size of markups in individual sectors, σ and ϕ_x are set such that Φ_x is equal to 10% in all sector; results for $\Phi = 5\%$ and $\Phi = 15\%$ are also reported.

Since σ is undetermined, this means that the same is true for the number of establishments, which is equal to (from 25):

$$N_x = \frac{1}{\sigma \mu_x}.$$

The competitiveness of a sector depends jointly on the elasticity of substitution between the sub-sectoral inputs, and the number of establishments competing in each sub-sector. What matters in the context of this model, then, is not the absolute number of competitors, but its volatility along the business

cycle; in any case, the number of competitors a given buyer faces in any (geographically or otherwise) fragmented sector cannot be easily determined.

Estimates for α , θ , γ , ζ_C and ζ_I are obtained from the 2002 sectoral use and make tables from NIPA's input-output accounts, following the methodology in Accolley and Gabler (2010) (see appendix B).

Table 1 contains a summary of some of the chosen parameters; the sector-specific parameters are listed in Appendix B.

4 Inferring Markup-Induced Movements in the Price of Investment

The goal here is to identify markup-induced movements in the relative price of investment from the observed series for the number of establishments. The chosen strategy is to use the model's equilibrium conditions to back out an expression for the price of investment as a function of the number of establishments in each sector.

Gross production in sector x is (equation 24):

$$Y_x = A_x K_x^{\alpha_x} L_x^{\theta_x} \prod_i M_{ix}^{\gamma_{ix}}. \quad (30)$$

Replacing K_x , L_x and M_{jx} by their optimal values from equations (21) through (23), and simplifying, one gets the following expression:

$$1 = (1 - \mu_x) P_x A \left[\frac{\alpha_x}{(r + \delta) P_I} \right]^{\alpha_x} \left[\frac{\theta_x}{w} \right]^{\theta_x} \prod_i \left[\frac{\gamma_{ix}}{P_i} \right]^{\gamma_{ix}}.$$

It follows that the logarithm for the price of good x is:

$$\log(P_x) = \Omega_x + \alpha_x \log[(r + \delta) P_I] + \sum_i [\gamma_{ix} \log P_i],$$

where

$$\begin{aligned} \Omega_x = & -\log(A) - \log(1 - \mu_x) - \alpha_x \log \alpha_x - \theta_x \log \theta_x \\ & + \theta_x \log w - \sum_i (\gamma_{ix} \log \gamma_{ix}). \end{aligned} \quad (31)$$

Table 2: Markup-induced Movements in the Price of Investment

Statistic ¹	Actual Series		Estimated Series		
	NIPA (a)	Cummins and Violante (2002) (b)	$\Phi = 5\%$ (c)	$\Phi = 10\%$ (d)	$\Phi = 15\%$ (e)
σ_{P_I/P_c}	0.68	0.71	0.06	0.12	0.23
$\sigma_{P_{I_e}/P_c}$	0.70	0.96	0.05	0.11	0.20

One can get a similar expression for the price of investment from equations (3) and (14):

$$\log(P_I) = \Psi + \sum_x \zeta_{xI} \log(P_x),$$

where

$$\Psi = - \sum_x \zeta_{xI} \log(\zeta_{xI}).$$

This leads to the following system of equations:

$$\begin{bmatrix} \log P_1 \\ \vdots \\ \log P_N \\ \log P_I \end{bmatrix} = \begin{bmatrix} \Omega_1 \\ \vdots \\ \Omega_N \\ \Psi \end{bmatrix} + \begin{bmatrix} \gamma' & \alpha' \log(r + \delta) \\ \zeta_I & 0 \end{bmatrix} \begin{bmatrix} \log P_1 \\ \vdots \\ \log P_N \\ \log P_I \end{bmatrix}, \quad (32)$$

which simply says that the price of good x depends on the price of inputs, weighted by their respective expenditure shares. Solving this system yields

$$\begin{bmatrix} \log P_1 \\ \vdots \\ \log P_N \\ \log P_I \end{bmatrix} = \left(\tilde{I}_{N+1} - \begin{bmatrix} \gamma' & \alpha' \log(r + \delta) \\ \zeta_I & 0 \end{bmatrix} \right)^{-1} \begin{bmatrix} \Omega_1 \\ \vdots \\ \Omega_N \\ \Psi \end{bmatrix}, \quad (33)$$

where $\tilde{I}_{N+1}$ is the identity matrix of size $N + 1$.

From equation (25), markups depend on the number of firms:

$$\mu_x = \frac{1}{\sigma N_x}.$$

Given the parameters estimated in section 3 and sector-specific time series for the number of establishments, one can then infer the movements in the price of investment that are induced by changes in the number of establishments, while keeping everything else constant.

The time series for the price of consumption (investment) is obtained by chain-linking commodities using the price series obtained above, weighing by commodity expenditure shares ζ_{xC} (ζ_{xI}), and dividing through by nominal consumption (investment). In the same way, one can obtain a price series for equipment investment, after subtracting construction expenditures from the commodity expenditure shares ζ_{xI} .

The U.S. Bureau of Labor Statistics' Business Employment Dynamics database² contains quarterly data on the number of establishments across 13 private non-farm sectors, for the years 1993:3 - 2009:3. The covered sectors are listed in Table 4. Without loss of generality, the number of establishments in each sector, N_x , is exponentially detrended, and σ is set such that the average markup over gross output is $\Phi_x = 10\%$.

The wage rate in (31) is obtained by dividing total employment expenditure from the 'use' table by total employment from the BLS Employment Dynamics database, for the year 2002. For the interest rate in (32), I use 1% per quarter.

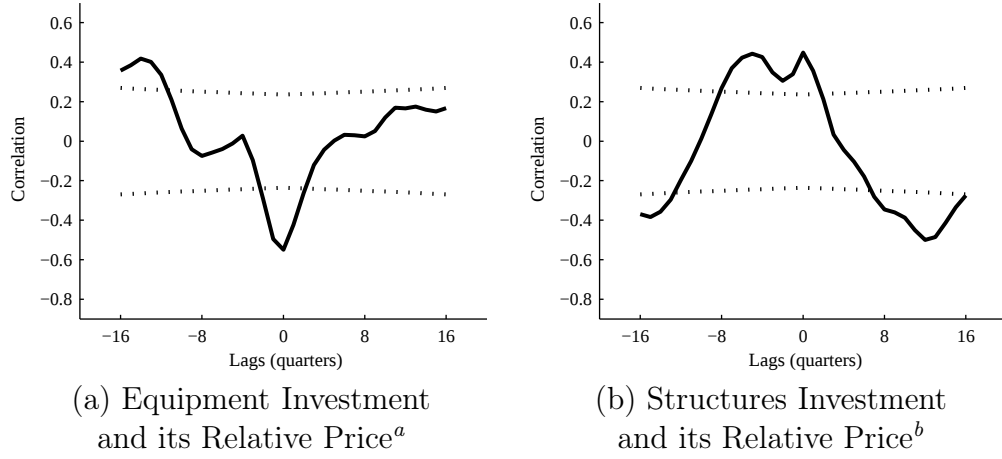
The observed negative correlation between total investment and its (relative) price stems from movements in the price of equipment (Figure 1a). Indeed, the price of structures is actually positively correlated with quantity (Figure 1b). Because of this, this paper focuses on the price of equipment when comparing volatilities. In practice, this choice does not matter much, because it turns out that within the sample period, the observed and estimated volatilities for total investment and equipment prices are very similar (Table 2, columns a, c, d, e).

As is well known, National Income and Product Accounts (NIPA) data underestimates the rate of technological progress in equipment investment. Based on Gordon's (1990) measures of the quality-bias in the official price indexes, Cummins and Violante (2002) constructed a quarterly series for the price of equipment investment. Their series is somewhat more volatile than NIPA's, but it ends in 2000, so that volatilities are reported both for NIPA data and for Cummins and Violante's corrected series.

The estimated series is significantly negatively correlated with equipment

²<http://www.bls.gov/bdm>

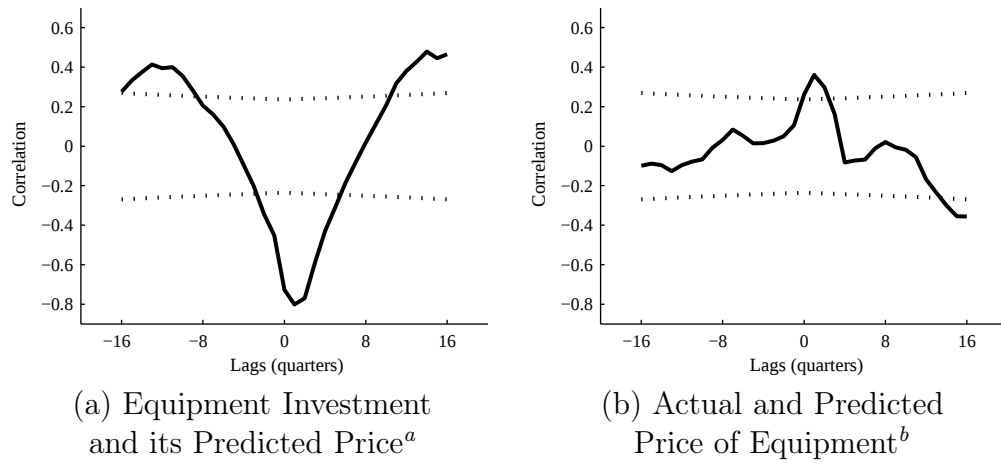
Figure 1: Cross-correlation Functions, Actual Prices



^aCorrelation between equipment investment at time t and its price in consumption units at various lags.

^bCorrelation between non-residential structures investment at time t and its price in consumption units at various lags.

Figure 2: Cross-correlation Functions, Predicted Prices



^aCorrelation between equipment investment at time t and its predicted price in consumption units at various lags.

^bCorrelation between the observed price of equipment investment in consumption units at time t and its predicted price at various lags.

investment (Figure 2a), which implies that the volatility in the number of establishments is higher for sectors which (directly or indirectly) produce many equipment investment goods. Also, the correlation between the actual and estimated series is .26, significant at the 5% level (Figure 2b).

The results are reported in Table 2. The variability of the estimated series for the price of equipment (second row) ranges between .05% and 0.20%, thus accounting for between 8% to 29% of the volatility in the price of equipment (between 5% and 21% if one takes Cummins and Violante’s series as the reference point). In the benchmark case, markup fluctuations account for slightly less than one-sixth of the fluctuations in the price of equipment investment (one-ninth using Cummins and Violante’s series).

5 Simulation

I now look at how much investment price volatility a multi-sector model with sector-specific markups can generate when all shocks are neutral. In order to maximize comparability with the analysis in Section 4, the simulated model features the same 13 sectors used in that section.

Table 3 contains a number of statistics characterizing the behavior of the U.S. economy over the sample period (column e), along with the corresponding statistics for the model. In order to obtain the series for aggregate output Y , consumption and investment are chain-weighted, as they are in the data.

Columns (b), (c) and (d) contain the results of simulating the model for an average gross markup of 5%, 10%, and 15%, which covers the range which is considered plausible in the literature, as discussed in the previous section. Column (f) lists the statistics for a standard one-sector model with no markups ($\Phi = 0$), no materials usage, and calibrated according to the procedure described in Section 3. For each case, the variance of the neutral shock, σ_ε , is set to replicate the observed volatility in aggregate output, σ_Y .

The multi-sector model does about as well—and sometimes better—at replicating standard business cycle moments than the one-sector model. Both models generate too little volatility in consumption. This is partly due to the fact that the calibration procedure described in Appendix B tends to underestimate sectoral labor shares, because it uses industry data on the compensation of employees, which does not include all of wage income—since capital income is less volatile, this makes consumption smoother. Because markup movements in (mainly) consumption-producing sectors counteract

these same movements in investment-producing ones, smoother consumption implies a lower volatility in the price of investment. However, it turns out that linearly increasing the labor income shares in all industries to match the 72% of total income found by Gomme and Rupert (2007) increases the volatility of consumption to .50%, but leaves the volatility of the price of investment virtually unchanged.

The model does reasonably well in replicating the high degree of comovement between consumption and investment which is observed in the data; however, higher markups lead to more fluctuations in the price of investment, which drives down comovement. The multi-sector model also generates more volatility in hours worked than the one-sector model. Because of the combined amplification effect of markups and materials usage on productivity, the standard error needed to replicate the observed output volatility is reduced on average by a factor three, when compared to the one-sector model.

As mentioned in the previous section, the paper focuses on explaining the observed movements in the price of equipment investment; hence, the volatility which is reported in column (a) is for the price of equipment investment. In the model, no distinction is made between different types of investment goods, so that implicitly the price of equipment will be equal to the price of total investment.

Due to the absence of other perturbations to the price of investment, the model implies that (equipment) investment and its relative price are perfectly negatively correlated; in the data, this correlation is $-.54$.

The model generates between 21% and 39% of the observed volatility of the price of investment (between 16% and 28% if one takes Cummins and Violante's (2002) equipment price series as a reference point). However, markup movements are not the only source of price fluctuations in the model: sectors which spend a higher than average share of their expenditure on materials are less affected by increases in factor prices during booms, so that their relative price goes down.

A simple measure for the materials intensity of consumption (investment) goods is the average sectoral materials expenditure share, weighed by the expenditure shares in the production of consumption (investment), which is equal to $\sum_x \sum_i \zeta_{xC} \gamma_{ix} / (\sum_x \sum_i \zeta_{xC} \gamma_{ix})$. This is 49% for consumption goods, and 59% for equipment investment (55% for total investment). Hence, amplification will be stronger in the investment sector, leading to a countercyclical movement in the price of investment. One can estimate this effect by calibrating the model for $\Phi = 10\%$ (the benchmark case; Table 3, column c), setting

Table 3: Business Cycle Statistics

Statistic ^a	Data	Multi-sector Model				One-sector Model $\Phi = 0$
		$\Phi = 5\%$	$\Phi = 10\%$	$\Phi = 15\%$	$\Phi = 0$	
	(a)	(b)	(c)	(d)	(e)	(f)
σ_Y	1.44	1.44	1.44	1.44	1.16	1.44
σ_C	0.74	0.38	0.40	0.40	0.35	0.35
σ_I	5.30	5.00	6.04	7.70	4.60	4.15
σ_L	1.12	0.78	0.78	0.80	0.59	0.67
$\sigma_{P_{I_e}/P_c}$	0.70	0.15	0.20	0.27	0.09	0
$\rho(C, I)$	79	72	66	53	77	76
$\rho(I, P_{I_e}/P_C)$	-54	-99	-99	-99	-99	-
σ_ε	-	0.360	0.294	0.225	0.294	0.880

^a σ_X denotes the standard deviation of variable X , and $\rho(X, Y)$ denotes the correlation between variables X and Y , where X and Y are logged and Hodrick-Prescott filtered prior to analysis. Both statistics are reported in percentage terms. All simulated moments are averages for 500 simulations of sample size 70.

markups to zero, and simulating the model. The results are listed in column (e): the implied volatility in the price of investment decreases to 0.09. Therefore, for the benchmark case ($\Phi = 10\%$), input share asymmetries account for 13% ($0.09/0.70$) of investment price movements, and markup movements for another 15%; the number for markup-induced movements is virtually the same as that found in Section 4.³

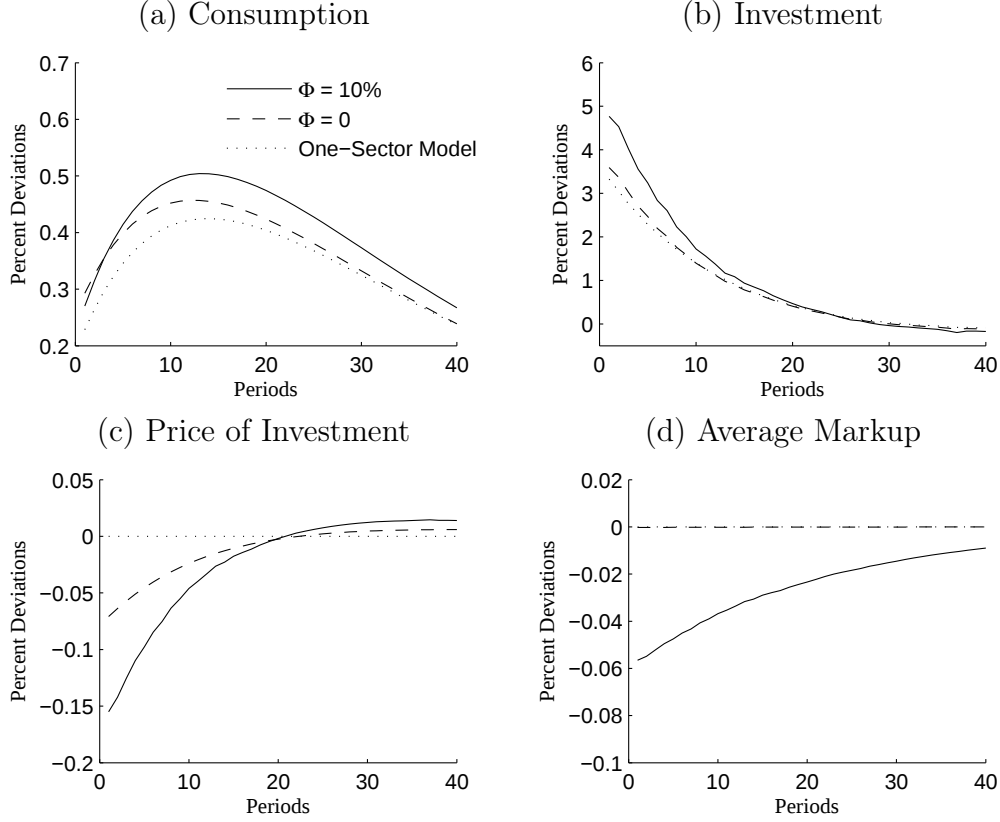
One may be concerned by the fact that entering and exiting establishments are on average of a smaller size than incumbents, which may limit their effect on markup movements. However, Jaimovich and Floetotto (2008) find that one-third of the cyclical volatility in job gains (losses) is explained by opening (closing) establishments. They also point out that the degree of competition in an economy depends not only on the number of establishments, but also on the number of franchises, which is strongly procyclical. They conclude that once one adopts a somewhat wider interpretation of what determines the number of competitors in a market, there is evidence for a sizeable variation in the degree of competition at the business cycle frequency.

Figure 3 contains the theoretical responses of some of the aggregate variables to a productivity shock, under various specifications. Responses for the full benchmark model are shown with full lines (labeled $\Phi = 10\%$), broken lines stand for the same model with markups set to zero ($\Phi = 0$), and dotted lines stand for the one-sector model described above. Markups and materials usage amplify the responses of consumption and investment (Figures 3a and 3b). The price of investment responds negatively in the case of the multi-sector model, not only in the benchmark case ($\Phi = 10\%$), but also when markups are set to zero, because of the asymmetries in materials usage mentioned above (Figure 3c).

The approach above has tried to answer the following question: how volatile would the price of investment be if there were only neutral shocks? Alternatively, one could ask how volatile it would be if there were no movements in sector-specific markups. For simplicity, I will assume that all of the relative price movements come from either markup fluctuations or investment-specific productivity shocks. Introducing investment shocks into

³Assuming that none of the costs an entering establishments faces are sunk greatly simplifies the model; it is also somewhat unrealistic. Inferring price movements directly from data on the number of establishments and comparing the results with simulated moments is also a way to check whether the simplified modeling of entry and exit has implications which are consistent with the data.

Figure 3: Impulse Responses



the model implies changing equation (3) to:

$$I = Q \prod_x I_x^{\zeta_{xI}},$$

where $Q_t = \exp(q_t)(1 + \gamma_q)^t$ is investment-specific productivity, with $\gamma_q \geq 0$ its growth rate and q_t a covariance stationary shock:

$$q_t = \varphi q_{t-1} + \varepsilon_{q,t}, \quad \varepsilon_{q,t} \sim N(0, \sigma_{\varepsilon_q}^2);$$

σ_ε and σ_{ε_q} are set in order to replicate the volatilities of aggregate output and the price of investment. The results are similar to those found above: when markups are set to zero, the volatility in the relative price drops from .70% to .62%, implying that sector-specific markup movements account for

.08 percentage points of the volatility of the price of investment, down from .11 previously.

6 Conclusion

In this paper, a multi-sector model was set up to examine the implications of endogenous markups and asymmetries in materials usage on the price of investment goods in consumption units. Both mechanisms were shown to lead to a temporary fall in the price of investment after a neutral technology shock, in the first case because of a stronger decrease in markups in (mainly) investment-producing sectors relative to those in consumption-producing ones; and in the second case because higher materials usage in investment-producing sectors lead to a stronger amplification of the shock in those sectors.

In the benchmark calibration with an average markup over gross production of 10%, the model implies that approximately one-sixth of the observed fluctuations in the price of investment can be attributed to movements in sector-specific markups. This finding is borne out both by direct observation of sectoral data on the number of establishments, and from simulating the model. Also, the simulated model implies that another one-sixth to one-seventh can be attributed to cross-sectoral differences in materials usage. In other terms, almost one-third of the fluctuations in the price of investment are due to purely neutral shocks.

I feel that this is an important finding. It indicates that purely investment-specific technology shocks may play a smaller role than previously thought, because neutral shocks also affect the price of investment negatively. This is consistent with Schmitt-Grohé and Uribe (Forthcoming), who find that identified investment-specific and neutral shocks are cointegrated.

In general, I feel that this model and results provide a richer framework in which to examine aggregate macroeconomic fluctuations. Much work, however, remains to be done. For example, the model could be used to estimate the relative size of markups across sectors, by replicating the volatility of output for each sector. Also, because the model is compatible with the input-output structure of national accounts, it can be used to extract information from industry-level data of any kind, which opens up a wide range of possible applications.

A The Case of a Two-Sector Model

There are two-sectors; output in the first (second) sector, labeled C (I), is used exclusively to make consumption (investment) goods. In other terms, the technology parameters for the production of consumption (investment) goods are

$$\begin{bmatrix} \zeta_{CC} & \zeta_{IC} \\ \zeta_{CI} & \zeta_{II} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix},$$

so that

$$C = Y_C$$

and

$$I = Y_I.$$

Using the factor price equations (21) - (23) to replace K_x , L_x and M_{ix} in sectoral output (24), we get, for $x \in \{C, I\}$:

$$Y_x = \left[\frac{\alpha Y_x}{(r + \delta) P_I} \right]^\alpha \left(\frac{\theta Y_x}{w} \right)^\theta \left[(1 - \mu_x) \gamma_{Cx} Y_x \frac{P_x}{P_C} \right]^{\gamma_{Cx}} \left[(1 - \mu_x) \gamma_{Ix} Y_x \frac{P_x}{P_I} \right]^{\gamma_{Ix}}.$$

Dividing Y_C by Y_I , and simplifying, the price of investment satisfies

$$\frac{P_I}{P_C} = \left[\frac{(1 - \mu_C)^{\gamma_{CC} + \gamma_{IC}}}{(1 - \mu_I)^{\gamma_{CI} + \gamma_{II}}} [(r + \delta) P_I]^{\alpha_I - \alpha_C} w^{\theta_I - \theta_C} \cdot \Theta \right]^{\frac{1}{\gamma_{CI} + \gamma_{IC}}},$$

where

$$\Theta = \frac{\alpha_C^{\alpha_C} \theta_C^{\theta_C} \gamma_{CC}^{\gamma_{CC}} \gamma_{IC}^{\gamma_{IC}}}{\alpha_I^{\alpha_I} \theta_I^{\theta_I} \gamma_{CI}^{\gamma_{CI}} \gamma_{II}^{\gamma_{II}}}$$

is a constant which equals zero if the model is symmetric, i.e., if technology parameters are the same in both sectors.

B Calibration Methodology

This section gives a brief explanation of the method used to calibrate the parameters α , θ and γ . I mostly follow the procedure in Accolley and Gabler

(2010); Basu et al. (2010) use a related methodology to estimate sector-specific technology shocks. The data consists of the 2002 benchmark ‘use’ and ‘make’ tables provided by NIPA, before redefinitions,⁴ aggregated into 13 sectors, which cover all of private non-farm output. The main difficulty is that the ‘make’ and ‘use’ tables list output and input expenditures in terms of industries, not in terms of commodities; since an industry may produce several commodities, one has to allocate expenditures to each commodity. The identification assumption will be that each commodity is produced using the same technology, no matter the producing industry.

The (transposed) ‘make’ table lists the (nominal) production of commodities for each industry:

$$\bar{M} = \begin{bmatrix} Y_{11}P_1 & \cdots & Y_{1N}P_1 \\ \vdots & \ddots & \vdots \\ Y_{N1}P_1 & \cdots & Y_{NN}P_N \end{bmatrix},$$

where Y_{xz} is the production of commodity x by industry z , and P_x is the price of commodity x ; N is the number of commodities (and industries).

The ‘use’ table lists (nominal) industry expenditure for materials (commodities), labor, and the gross operating surplus;⁵ its first N columns are

$$\bar{U} = \begin{bmatrix} M_{11}P_1 & \cdots & M_{1N}P_N \\ \vdots & \ddots & \vdots \\ M_{N1}P_1 & \cdots & M_{NN}P_N \\ L_1w & \cdots & L_Nw \\ s_1 & \cdots & s_N \end{bmatrix},$$

where M_{xz} is the quantity of commodity x used as an input by industry z ; L_z is the quantity of labor used by industry z ; and s_z is gross operating surplus.

Within each industry, commodities are produced by a representative firm using capital, labor and a range of commodities as inputs (equation 24); the technology for producing a given commodity is the same in all industries:

$$Y_{xz} = A_{xz} K_{xz}^{\alpha_x} L_{xz}^{\theta_x} \prod_i M_{i,xz}^{\gamma_{ix}},$$

⁴NIPA makes some adjustments to industry and commodity definitions before using those tables to estimate GDP.

⁵Both tables are available at <http://www.bea.gov/industry/iotables>.

where $M_{i,xz}$ is the amount of commodity i used by industry z to produce commodity x . The first-order condition on $M_{i,xz}$ is

$$M_{i,xz}P_i = (1 - \mu_x) \gamma_{ix} Y_{xz} P_x.$$

Dividing each side by the total nominal production of industry z , $\sum_x Y_{xz} P_x$, aggregating on both sides over all commodities x , and assuming that markups are the same for all commodities, we get

$$\frac{M_{iz}P_i}{\sum_x Y_{xz}P_x} = (1 - \mu) \frac{\sum_x \gamma_{ix} Y_{xz} P_x}{\sum_x Y_{xz} P_x},$$

which is equal to

$$\bar{u}_{iz} = (1 - \mu) \sum_x \gamma_{ix} \bar{m}_{xz},$$

where $\bar{u}_{iz} = \bar{U}_{iz} / \sum_x \bar{U}_{xz}$, and $\bar{m}_{xz} = \bar{M}_{xz} / \sum_x \bar{M}_{xz}$; notice that $\sum_x \bar{U}_{xz} = \sum_x \bar{M}_{xz}$. Similarly, from the first-order conditions on labor (22):

$$\bar{u}_{Nz} = (1 - \mu) \sum_x \theta_x \bar{m}_{xz}.$$

In matrix notation,

$$\bar{u} = (1 - \mu) \begin{bmatrix} \gamma \\ \theta \end{bmatrix} \bar{m},$$

so that

$$\begin{bmatrix} \gamma \\ \theta \end{bmatrix} = \frac{\bar{u} \cdot \bar{m}^{-1}}{1 - \mu}.$$

α , the technology parameter vector for capital, is recovered from the constant returns to scale condition:

$$\alpha_x = 1 - \theta_x - \sum_i \gamma_{ix}.$$

From the first-order conditions on C_x and I_x (equations 13 and 14), the sectoral expenditure shares for producing consumption and investment goods are:

$$\begin{aligned} \zeta_{xc} &= \frac{C_x P_x}{C P_C} \quad , \\ \zeta_{xi} &= \frac{I_x P_x}{I P_I} \quad . \end{aligned}$$

$C_x P_x$ and $I_x P_x$ are the total consumption and investment expenditures in commodity x ; they are listed in the latter columns of the ‘use’ table, under the heading ‘final use.’

The resulting parameters are, for $\Phi = 10\%$:

$$\begin{aligned} \alpha &= [.2388 \quad .2677 \quad .0646 \quad .0448 \quad .0949 \quad .0896 \quad .0398 \quad .2233 \quad .4950 \quad .0886 \quad .0005 \quad .0576 \quad .1094], \\ \theta &= [.1819 \quad .2199 \quad .5556 \quad .2253 \quad .4961 \quad .4915 \quad .4010 \quad .2471 \quad .1966 \quad .5342 \quad .5687 \quad .4376 \quad .3877], \\ \gamma &= \begin{bmatrix} .0571 & .2438 & .0051 & .0434 & .0001 & .0001 & .0023 & .0003 & .0001 & .0002 & .0003 & .0006 & .0004 \\ .0367 & .0014 & .0038 & .0214 & .0079 & .0185 & .0083 & .0062 & .0076 & .0051 & .0154 & .0290 & .0132 \\ .0465 & .0285 & .0006 & .0037 & .0014 & .0035 & .0091 & .0074 & .0057 & .0028 & .0023 & .0048 & .0067 \\ .0844 & .032 & .1826 & .4113 & .0601 & .0735 & .1304 & .0728 & .0066 & .0385 & .0967 & .1341 & .0906 \\ .0130 & .0052 & .0215 & .0586 & .0444 & .0192 & .0168 & .0093 & .0031 & .0049 & .0163 & .0230 & .0146 \\ .0028 & .0001 & .0154 & .0028 & .0009 & .0023 & .0047 & .0001 & .0002 & .0005 & .0019 & .0034 & .0123 \\ .0237 & .0886 & .0118 & .0267 & .0448 & .0394 & .1390 & .0153 & .0039 & .0132 & .0089 & .0136 & .0176 \\ .0033 & .0042 & .0074 & .0094 & .0124 & .0136 & .0128 & .1915 & .0107 & .0298 & .0163 & .0148 & .0243 \\ .1631 & .0338 & .0327 & .0266 & .0627 & .1157 & .0972 & .0582 & .1861 & .0839 & .1236 & .0937 & .1831 \\ .1452 & .0561 & .0811 & .1151 & .1577 & .1166 & .1169 & .1346 & .0690 & .1620 & .1080 & .1393 & .1050 \\ .0001 & .0005 & .0001 & .0001 & .0005 & .0025 & .0001 & .0005 & .0001 & .0003 & .0185 & .0006 & .0043 \\ .0012 & .0154 & .0028 & .005 & .0062 & .0057 & .0104 & .0241 & .0089 & .0237 & .0117 & .0340 & .0158 \\ .0021 & .0027 & .0150 & .0059 & .0100 & .0089 & .0115 & .0092 & .0065 & .0123 & .0112 & .0139 & .0150 \end{bmatrix}. \end{aligned}$$

The parameters are listed in the order given by Table 4.

C Data

When series are added together they are chain-weighted. The sample period is 1992:3 - 2009:3.

Residential investment is removed from the data by subtracting the categories for new residential construction and owner-occupied dwellings from the ‘use’ and ‘make’ tables. Durable consumption is not removed due to identification problems.

All aggregate quantities are expressed in per capita terms, by dividing the original series by the U.S. Bureau of Labor Studies’ (BLS) series for total workers. Consumption C is private non-durable consumption; I is private investment in equipment and software and non-residential structures. L corresponds to average weekly hours in the private sector, multiplied by total workers; both series are from the BLS.

Table 4: List of Production Sectors

	I.O. Code	Name
1	21	Mining
2	22	Utilities
3	23	Construction
4	31-33	Manufacturing
5	42	Wholesale trade
6	4A	Retail trade
7	48-49	Transportation and warehousing
8	51	Information
9	52	Finance, insurance, real estate, rental, and leasing
10	53-56	Professional and business services
11	61-62	Educational services, health care, and social assistance
12	71-72	Arts, entertainment, recreation, accommodation, and food services
13	81	Other services, except government

References

- Accolley, D., Gabler, A., 2010. Measuring private consumption and investment sector’s physical capital stocks. mimeo.
- Basu, S., Fernald, J., Fisher, J., Kimball, M., 2010. Sector-specific technical change. mimeo.
- Bloch, H., Olive, M., 2001. Pricing over the cycle. *Review of Industrial Organization* 19 (1), 99–108.
- Boldrin, M., Christiano, L. J., Fisher, J. D., 2001. Habit persistence, asset returns, and the business cycle. *American Economic Review* 91 (1), 149–166.
- Collard, F., Juillard, M., 2001. A higher-order taylor expansion approach to simulation of stochastic forward-looking models with an application to a nonlinear phillips curve model. *Computational Economics* 17 (2), 125–139.
- Cummins, J., Violante, G. L., 2002. Investment-specific technical change

- in the us (1947-2000): Measurement and macroeconomic consequences. *Review of Economic Dynamics* 5 (2), 243–284.
- Dos Santos Ferreira, R., Lloyd-Braga, T., 2005. Non-linear endogenous fluctuations with free entry and variable markups. *Journal of Economic Dynamics and Control* 29 (5), 847–871.
- Fisher, J. D., 2006. The dynamic effects of neutral and investment-specific technology shocks. *Journal of Political Economy* 114 (3).
- Gali, J., Zilibotti, F., 1995. Endogenous growth and poverty traps in a cournotian model. *Annales d'Economie et de Statistique* 37/38 (3), 197–214.
- Gomme, P., Rupert, P., 2007. Theory, measurement and calibration of macroeconomic models. *Journal of Monetary Economics* 54 (2), 460–497.
- Gordon, R. J., 1990. *The Measurement of Durable Goods Prices*. University of Chicago Press.
- Greenwood, J., Hercowitz, Z., Krusell, P., 2000. The role of investment-specific technological change in the business cycle. *European Economic Review* 44 (1), 91–115.
- Hornstein, A., Praschnik, J., 1997. Intermediate inputs and sectoral comovement in the business cycle. *Journal of Monetary Economics* 40 (3), 573–595.
- Horvath, M., 2000. Sectoral shocks and aggregate fluctuations. *Journal of Monetary Economics* 45, 69–106.
- Jaimovich, N., Floetotto, M., Jan 2008. Firm dynamics, markup variations, and the business cycle. *Journal of Monetary Economics* 55, 1238–1252.
- Justiniano, A., Primiceri, G., 2008. The time-varying volatility of macroeconomic fluctuations. *The American Economic Review* 98 (3), 604–641.
- Justiniano, A., Primiceri, G., Tambalotti, A., Forthcoming. Investment shocks and the relative price of investment. *Review of Economic Dynamics*.
- Monacelli, T., 2009. New keynesian models, durable goods, and collateral constraints. *Journal of Monetary Economics* 56, 242–254.

- Ngai, L., Samaniego, R., 2009. Mapping prices into productivity in multisector growth models. *Journal of economic growth* 14 (3), 183–204.
- Ramey, V., 1996. NBER macroeconomics annual, 268–275.
- Rotemberg, J., Woodford, M., 1999. The cyclical behavior of prices and costs. *Handbook of macroeconomics* 1, 1051–1135.
- Schmitt-Grohé, S., Uribe, M., 2008. What’s news in business cycles. NBER Working Paper.
- Schmitt-Grohé, S., Uribe, M., Forthcoming. Business Cycles With A Common Trend in Neutral and Investment-Specific Productivity. *Review of Economic Dynamics*.