NBER WORKING PAPER SERIES

LUMPY INVESTMENT, LUMPY INVENTORIES

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Working Paper 17924
http://www.nber.org/papers/w17924

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
March 2012

We thank Francois Gourio for his discussion. We are grateful to participants at the ASSA (2012 meeting in Chicago) for their comments. Any remaining errors are our own. The views expressed herein are those of the authors and do not necessarily reflect the views of the National Bureau of Economic Research.

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JEL No. E20,E22,E3,E32

ABSTRACT

How do microeconomic frictions and microeconomic heterogeneity affect macroeconomic dynamics? We revisit the recent claim in the literature that nonconvex capital adjustment costs do not matter for aggregate dynamics. We argue that the neutrality of fixed adjustment frictions in general equilibrium hinges on the assumption of capital good homogeneity. With only one type of capital good to save and invest in, fixed capital investment dynamics are tightly linked to consumption dynamics, which are similar across lumpy and frictionless investment models. With capital goods heterogeneity, households optimally substitute between different ways of saving, which renders their consumption/saving decisions more sensitive to capital adjustment frictions. We quantify our arguments by introducing inventories into a two-sector lumpy investment model. We find that with inventories, frictionless fixed capital adjustment leads to an initial response of fixed capital investment to productivity shocks that is 50% higher than with capital adjustment frictions, calibrated to the fraction of plants undergoing lumpy investment episodes. We argue more generally that the details of how general equilibrium is introduced into the physical environment of a model matters for the aggregate relevance of microeconomic frictions and microeconomic heterogeneity.

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1 Introduction

How do microeconomic frictions and microeconomic heterogeneity affect macroeconomic dynamics? As a specific example take Thomas (2002), Khan and Thomas (2003) and Khan and Thomas (2008) who argue in a series of papers that nonconvexities in the capital adjustment technology at the micro level have little impact on aggregate dynamics, as general equilibrium price movements tend to offset the effects of these frictions. Models with nonconvex capital adjustment costs deliver lumpy investment patterns at the micro level, but also feature aggregate business cycle statistics that are quantitatively similar to standard RBC models, once real wages and real interest rates adjust to clear markets.

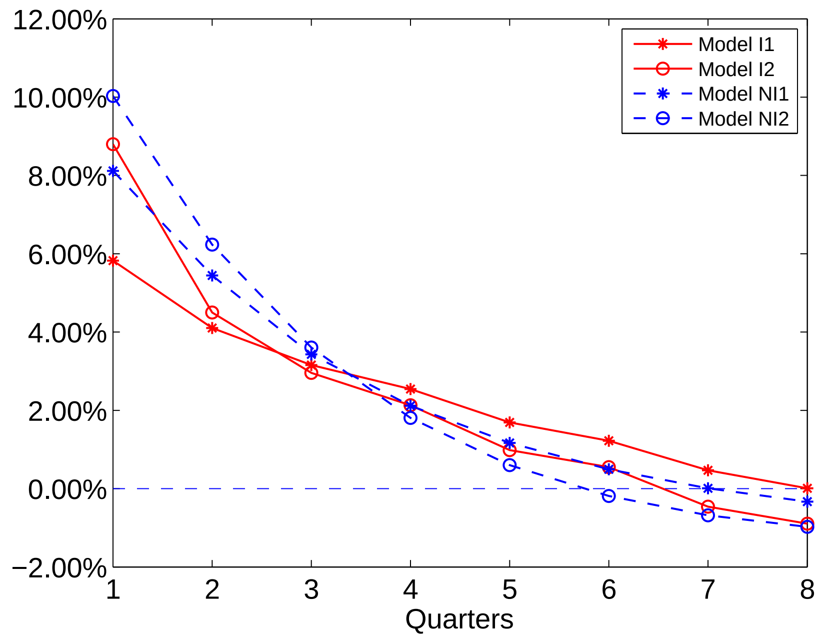
Intuitively, this "neutrality result" can be understood from the first order conditions of the representative household. With a representative household, the intratemporal and intertemporal first order conditions govern the optimal paths of consumption and labor supply, which in turn govern the optimal paths of output/income and saving in the short run. Thus, the households in a lumpy investment model *would like* to follow the same saving path as in the frictionless model; after all the household side is the same in both models. The question is, whether they *are able* to do so when adjusting the capital stock is costly. The answer turns out to be yes, as long as the households can substitute between the extensive and intensive margins of investment (see Gourio and Kashyap (2007) for this insight). To be concrete, facing a positive aggregate productivity shock, households use investment to increase consumption in the future. In a frictionless model they do this entirely through the intensive margin of investment: every firm invests a little more. With nonconvex capital adjustment costs this is no longer optimal, instead a few firms invest a lot. Households concentrate the desired amount of investment into a few firms which really need to invest, and recover essentially the same aggregate saving/investment path as in a frictionless model.

This intuition rests on the assumption that there is only one type of capital good, fixed capital, that firms can invest in and households can save in. This is the dual role of fixed capital in standard models: factor of production and the only means of saving, which in turn implies the familiar equality between saving and (fixed capital) investment. Thus for the economy as a whole investment and consumption dynamics are tightly linked. However, in reality people may save through multiple channels. We show that aggregate investment in fixed capital is more sensitive to nonconvex adjustment costs even in general equilibrium, once we introduce multiple channels of saving.

The key intuition for this result is the substitution between different saving channels. Introducing more saving channels offers more margins of choice to the households, in addition to the extensive/intensive margin choice in fixed capital investment: they can switch optimally into other ways of saving to smooth consumption, if adjusting fixed capital is costly. As a result, the investment decisions in fixed capital will be more sensitive to the frictions in capital adjustment. Viewed from another perspective, extra saving channels enhance the households' ability to smooth consumption, which in turn implies smoother interest rate movements. Smoother interest rate movements bring the dynamics of the general equilibrium model closer to those in a partial equilibrium model, where lumpiness is known to matter. Note that there is a general insight here: when aggregate resource constraints and general equilibrium effects are important for aggregate dynamics, the precise details of *how* these general equilibrium effects are introduced into the physical environment matter.

We study the implications of multiple saving vehicles for the "neutrality question" in a quantitative DSGE model. We extend the model in Khan and Thomas (2003) into a two-sector setting with an intermediate goods sector and a final goods sector. At the same time, we incorporate a second way of saving: inventories. The final goods sector has the opportunity to store the output from the intermediate goods sector as inventories. The incentive to hold inventories is generated by fixed ordering costs for shipments from the intermediate goods to the final goods sector. Viewed from a different angle, we build on the inventory model in Khan and Thomas (2007) and add nonconvex capital adjustment costs in the intermediate goods sector. We choose inventories as the second capital type because, 1) it is a highly cyclical component in the national accounts and, 2) it is a natural saving vehicle to buffer against shocks in the short-run. Methodologically, our paper provides the first quantitative analysis of how nonconvex capital adjustment frictions impact aggregate dynamics in the presence of capital good heterogeneity.

Figure 1: Impulse Response Function of Fixed Investment



Notes: This figure shows the impulse response functions of fixed capital investment to a one standard deviation aggregate productivity shock in the intermediate goods sector. 'Model I1' has the baseline calibrated nonconvex fixed capital adjustment cost parameter and the baseline calibrated inventory order cost parameter. 'Model I2' has zero nonconvex fixed capital adjustment cost and the baseline inventory order cost parameter. 'Model NI1' has the baseline calibrated nonconvex fixed capital adjustment cost parameter and zero inventories. 'Model NI2' has zero nonconvex fixed capital adjustment cost and zero inventories. The difference between the IRFs of 'Model I2' and 'Model I1' is the effect of nonconvex fixed capital adjustment costs in the presence inventories. The difference between the IRFs of 'Model NI2' and 'Model NI1' is the effect of nonconvex fixed capital adjustment costs without inventories. There is no need to recalibrate the fixed capital adjustment cost parameter or the inventory order cost parameter, as our calibration targets, being long-run targets, are not sensitive across model specifications.

Figure 1 summarizes our findings. It shows the impulse response functions of fixed capital investment to a one standard deviation productivity shock. The nonconvex fixed capital adjustment costs dampen the initial response of fixed capital investment to a productivity shock by 2.99 percentage points in the presence of inventories ('Model I1' versus 'Model I2'). That is, the 'no capital adjustment costs'-impact response is approximately 50% higher than the one with capital adjustment costs. In contrast, without inventories nonconvex fixed capital adjustment costs dampen the initial response of fixed capital investment to a productivity shock by only 1.91 percentage points ('Model NI1' versus 'Model NI2'). That is, the 'no capital adjustment costs'-impact response is only 24% higher than the one with capital adjustment costs. In addition, with inventories the response of investment in the model with the baseline level of nonconvex fixed capital adjustment costs is flatter than that in the model without these capital adjustment frictions. This means that with inventories nonconvex capital adjustment costs stretch the propagation of the productivity shock by more than capital adjustment frictions can do without inventories.

Figure 1 also shows that inventories dampen the impact response of fixed capital investment at every level of fixed capital adjustment costs. With a positive productivity shock households' higher demand for saving can be partially satisfied by inventories, which are now relatively cheap to produce. And this is done the more so, the higher the nonconvex fixed capital adjustment is, i.e. the more costly the usage of fixed capital is as a saving vehicle: 10.01% impact response versus 9.01% impact response in the frictionless fixed capital adjustment model, yet 8.10% impact response versus 6.02% impact response in the model with the baseline calibrated nonconvex fixed capital adjustment cost parameter.

Another direct implication of our mechanism is that the households' ability to smooth consumption is enhanced by capital goods heterogeneity. This is because multiple ways of saving expand the agents' choice set when it comes to consumption smoothing. The consumers are able to move closer to their first-best consumption/saving choices when they can save in both inventories and fixed capital. In the end, inventories partially offset the hindering effect on consumption smoothing introduced by fixed capital adjustment frictions. The impulse response functions of consumption to an aggregate productivity shock from the lumpy investment model and the frictionless adjustment model are very similar when inventories exist. Similarly, the volatility and persistence of aggregate consumption are much less sensitive to fixed capital adjustment frictions in models with inventories.

Our paper speaks to the debate on the aggregate neutrality of nonconvex fixed capital adjustment frictions. As mentioned, Thomas (2002), Khan and Thomas (2003) and Khan and Thomas (2008) come down on the neutrality side. Similarly, House (2008) argues that fixed adjustment costs are irrelevant for aggregate dynamics when the depreciation rate of fixed capital approaches zero, as firms are nearly indifferent regarding the timing of investment. Miao and Wang (2011), in an analytical framework, provide specific conditions on preferences, technology and the fixed adjustment cost distribution under which fixed adjustment costs are neutral for business cycles dynamics.

On the other side of the debate are Gourio and Kashyap (2007) and Bachmann et al. (2011), who argue that the neutrality results in Thomas (2002), Khan and Thomas (2003) and Khan and Thomas (2008) are specific to their calibration strategy and inconsistent with some nonlinear aspects of the time series of the aggregate investment rate in the U.S. These papers on both sides share the 'one capital good'-set-up. Another paper related to ours is Fiori (2012), which also features lumpy capital adjustment in a two-sector model and non-neutrality results. The non-neutrality there is caused by movements of the relative price of investment, which in our set up is constant by assumption. In addition, and related to our results, Johnston (2009) and Reiter et al. (2011) show that investment lumpiness matters in the aggregate in models with sticky prices.

The rest of the paper proceeds as follows. Section 2 outlines the model. Section 3 discusses the calibration and model solution. Section 4 presents the results. Section 5 concludes.

2 The Model

2.1 The Environment

There are three kinds of agents in the economy: final goods producers, intermediate goods producers and households. The final goods producers use the intermediate goods, of which they hold inventories in equilibrium, and labor to produce the final goods. Final output can be either consumed or invested as fixed capital. The intermediate goods producers combine fixed capital and labor to produce the intermediate goods. Households consume final goods and provide homogeneous labor to both types of producers. They own all the firms. They receive wage and dividend payments from both types of firms and purchase their consumption goods from the final goods producers. All markets are competitive. We impose nonconvex fixed capital adjustment costs in the intermediate good sector.

2.1.1 The Final Goods Producers

There is a continuum of final goods producers. They use intermediate goods, m, and labor, n, to produce the final output through a production function $G(m, n)$. The production function is strictly concave and has decreasing returns to scale. Whenever the final goods producers purchase intermediate goods, they face a fixed cost of ordering and delivery, denoted in units of labor, ϵ. To avoid incurring the fixed cost frequently, the final good producers optimally hold a stock of inventories of the intermediate goods. Denote the inventory level for an individual producer as $s \in \mathbb{R}_+$.

The final goods producers differ in their fixed cost parameter for ordering, $\epsilon \in [0, \bar{\epsilon}]$. In each period, this parameter is drawn independently for every firm from a time invariant distribution $H(\epsilon)$. At the beginning of the period, a typical final firm starts with its stock of inventories, s, inherited from the previous period. It also learns its fixed cost parameter, ϵ. The firm decides whether to adjust its inventory level. If the firm adjusts, it pays the fixed cost and chooses a new inventory level. Otherwise, the firm enters the production phase with the inherited inventory level s. We denote the quantity of adjustment by x_m. The inventory stock ready for production is $s_1 = s + x_m$, with $x_m = 0$ if the firm does not adjust.

After the inventory decision the firm determines its labor input, n, and the intermediate goods input, $m \in [0, s_1]$, for current production. Intermediate goods are used up in production. The remaining stock of intermediate goods, $s' = s_1 - m \geq 0$, is the starting stock of inventories for the next period. Stored inventories incur a unit cost of σ, denoted in units of final output. In the end, the output of a typical final firm is $y = G(m, n) - \sigma s'$.

2.1.2 Intermediate Goods Producers

There is a continuum of intermediate goods producers. They are subject to an aggregate productivity shock, which is the sole source of aggregate uncertainty.[1] Let z denote the aggregate productivity level. It follows a Markov chain, $z \in \{z_1, \cdots, z_{N_z}\}$, where $P(z' = z_j | z = z_i) = \pi_{ij} \geq 0$ and $\sum_{j=1}^{N_z} \pi_{ij} = 1$ for all i.

[1] As pointed out in Khan and Thomas (2007), placing aggregate productivity in the intermediate sector is necessary in this physical environment to generate a countercyclical relative price of intermediate goods, a feature found in the U.S. data.

Each firm produces with fixed capital and labor. Whenever the firm decides to adjust its capital stock, it has to pay a fixed cost, denoted in units of labor. In each period, the cost to adjust capital is drawn independently for every firm from a time invariant distribution $I(\zeta)$. A typical intermediate good producer is identified by its capital stock, k, and its cost to adjust capital, $\zeta \in [0, \overline{\zeta}]$.

At the beginning of each period, the firm learns aggregate productivity, z, and its idiosyncratic cost to adjust capital, ζ. It starts with a fixed capital stock, k, inherited from the previous period. First, it decides about the labor input, l. It combines l and k according to a production function $zF(k, l)$. The $F(\cdot)$ function is strictly concave and has decreasing returns to scale.[2] After production, the firm chooses whether to adjust its capital stock. It can pay a fixed cost to adjust its capital stock by investing i. In this case, the new capital stock for the next period in efficiency units is $k' = [(1 - \delta)k + i]/\gamma$, where δ is the depreciation rate and γ is the steady state growth rate of the economy. Alternatively, the firm can avoid the adjustment cost and start the next period with the depreciated capital stock $k' = (1 - \delta)k/\gamma$.

2.1.3 Households

We assume a continuum of identical households who value consumption and leisure. They have access to a complete set of state-contingent claims. Households own all the firms. They provide labor to the firms and receive wage and dividend payments.

The households have the following felicity function:

$$u(c, n^h) = \log c - A^h n^h,$$

where n^h is the total hours devoted to market work.

2.2 Competitive Equilibrium

2.2.1 Aggregate State Variables

In addition to z, the aggregate productivity level, two endogenously determined distributions are aggregate state variables in this model: the distribution of the firm-specific inventory stocks, $\mu(S)$, and the distribution of firm-specific fixed capital stocks, $\lambda(K)$. Both S and K are subsets of a Borel algebra over $\mathbb{R}_+$.

The aggregate state variables are summarized as (z, A), where $A = (\mu, \lambda)$. The distribution of μ evolves according to a law of motion $\mu' = \Gamma_\mu(z, A)$, and similarly, the distribution of λ evolves according to $\lambda' = \Gamma_\lambda(z, A)$.

The final good is the numeraire. Workers are paid $\omega(z, A)$ per unit of labor input. The intermediate goods are traded at $q(z, A)$ per unit.

[2] As Miao and Wang (2011) show, fixed adjustment costs cannot be expected to have a large impact with constant return to scale. We follow the majority of the literature, e.g. Bachmann et al. (2011), Bloom (2009), Gourio and Kashyap (2007) as well as Cooper and Haltiwanger (2006), and use a decreasing returns to scale assumption.

2.2.2 Problem of the Household

The households receive a total dividend payment $D(z, A)$ and labor income $n^h(z, A)\omega(z, A)$ from the firms. In each period the households determine how much to work and how much to consume. All we need from the household problem is an intertemporal and an intratemporal first order condition.

We can express the dynamic programming problems for both types of firms with the marginal utility of consumption as the pricing kernel:

$$p(z, A) = \frac{1}{c(z, A)}.$$

Then every firm weighs its current profit by this pricing kernel and discounts its future expected earnings by β. This changes the unit of the firm's problems in both sectors to utils but leaves the policy functions unchanged.

The first-order conditions also imply that the real wage is given by:

$$\omega(z, A) = \frac{A^h}{p(z, A)}.$$

2.2.3 Problem of Final Goods Producers

Let V_0 be the value of a final goods producer at the beginning of a period after the inventory adjustment cost parameter is realized and before any inventory adjustment and production decisions. Let V_1 be the expected value function after the adjustment decision but before the production decision. Given the aggregate laws of motion Γ_μ and Γ_λ, the firm's problem is characterized by the following three equations. For expositional ease, the arguments for functions other than the value functions are omitted.

$$V_0(s, \epsilon; z, A) = pqs + \max\Big\{ - p\omega\epsilon + V_a(z, A), -pqs + V_1(s; z, A)\Big\}, \tag{1}$$

$$V_a(z, A) = \max_{s_1 > 0}\{-pqs_1 + V_1(s_1; z, A)\}, \tag{2}$$

and:

$$\begin{aligned} V_1(s_1; z, A) = \max_{n \geq 0, s_1 \geq s' \geq 0} \Big\{ & p[G(s_1 - s', n) - \sigma s' - \omega n] \\ & + \beta E_z \Big[\int_0^{\bar{\epsilon}} V_0(s', \epsilon; z', A') d(H(\epsilon)) \Big] \Big\}. \end{aligned} \tag{3}$$

The expectation is taken over z', next period's aggregate productivity.

Equation (1) describes the binary inventory adjustment decision of the firm. The firm adjusts if the value of entering the production phase with the optimally adjusted inventory level, described by $V_a(\cdot)$ in equation (2), minus the cost of adjustment, exceeds the value of directly entering the production phase with the inherited inventory level, $V_1(s; z, A)$.

The solution to equation (1) amounts to a cut-off rule in ϵ. The firm adjusts if:

$$-p\omega\epsilon + V_a(z, A) \geq -pqs + V_1(s; z, A).$$

Therefore the cut-off value is:

$$\widetilde{\epsilon}(s; z, A) = \frac{V_a(z, A) - V_1(s; z, A) + pqs}{p\omega}.$$

Given the support of the adjustment cost distribution, this cut-off value is modified to:

$$\epsilon^* = \max(0, \min(\overline{\epsilon}, \widetilde{\epsilon})).$$

The firm adjusts if its draw is smaller than or equal to $\epsilon^*(s; z, A)$.

Equation (2) describes the value of inventory adjustment. The solution to this equation is the optimal target level of inventory, $s_1^*(s, \epsilon; z, A)$. Note that the optimization problem, which is formulated in terms of the stock of inventories, s, instead of order flows, does not depend on any firm-specific characteristics. Therefore in any period, all the adjusting firms choose the same inventory target level, $s_1^*(z, A)$.

Equation (1) and (2) jointly determine the production-time inventory level, s_1:

$$s_1(s, \epsilon; z, A) = \begin{cases} s_1^*(z, A) & \text{if } \epsilon \leq \epsilon^*(s; z, A) \\ s & \text{if } \epsilon > \epsilon^*(s; z, A) \end{cases}.$$

Equation (3) describes the production phase. The firm finds the optimal inventory level for the next period and the optimal employment level for this period. The decision for next period's inventory level, s', is equivalent to deciding about the amount of intermediate goods to be used up in current production.

The solution for employment does not depend on the continuation value function. Therefore, given s', it is the analytical solution to:

$$\frac{\partial G(s_1 - s', n^*)}{\partial n} = \omega.$$

The optimal employment and inventory usage decision jointly imply the optimal output level:

$$y^*(s_1; z, A) = G(s_1 - s'^*(s_1; z, A), n^*(s_1; z, A)) - \sigma s'^*(s_1; z, A).$$

2.2.4 Problem of the Intermediate Goods Producers

Let W_0 be the value function of the intermediate good producers prior to the realization of the adjustment cost parameter ζ. Let W_1 be the value function after the realization of ζ.

The intermediate good producer's problem can be summarized by the following equation:

$$W_1(k,\zeta;z,A) = \max_l \Big\{ p \cdot [q \cdot zF(k,l) - l\omega] + \max\{W_i(k;z,A), -p\zeta\omega + W_a(k;z,A)\} \Big\}, \tag{4}$$

where:

$$W_a(k;z,A) = \max_{k'} \{-(\gamma k' - (1-\delta)k)p + \beta E_z[W_0((k';z',A')]\}, \tag{5}$$

$$W_i(k;z,A) = \beta E_z[W_0((1-\delta)k/\gamma;z',A')], \tag{6}$$

$$W_0(k;z,A) = \int_0^{\overline{\zeta}} W_1(k,\zeta;z,A)d(I(\zeta)). \tag{7}$$

The expectation in equation (5) and (6) is taken over z', next period's aggregate productivity.

In equation (4), the firm first solves for the optimal employment, given the fixed capital stock. The solution is :

$$\frac{\partial qzF(k,l^*)}{\partial l} = \omega.$$

After the production decision, the firm solves the binary fixed capital adjustment decision. The firm adjusts if the expected value from the optimally adjusted fixed capital stock, given in equation (5), minus the cost of adjustment, exceeds the expected value from the unadjusted fixed capital stock, given in equation (6).

The solution to the adjustment decision follows a cut-off rule for ζ. The firm adjusts if:

$$-p\omega\zeta + W_a(k;z,A) \geq W_i(k;z,A).$$

Therefore the cut-off value for ζ is:

$$\widetilde{\zeta}(k;z,A) = \frac{W_a(k;z,A) - W_i(k;z,A)}{p\omega}.$$

The restriction from the support of the cost distribution applies, so that

$$\zeta^* = \max(0, \min(\overline{\zeta}, \widetilde{\zeta})).$$

The firm adjusts to the target capital stock if its adjustment cost is smaller than or equal to $\zeta^*(k;z,A)$.

The optimal adjustment target for fixed capital is given by the solution to equation (5). Although the value function depends on the level of individual capital stocks, the resulting policy function, k^*, does not. After the binary adjustment decision, the capital stock for the next period is:

$$k'(k;z,A) = \begin{cases} k^*(z,A) & \text{if } \zeta \leq \zeta^*(k;z,A) \\ (1-\delta)k/\gamma & \text{if } \zeta > \zeta^*(k;z,A) \end{cases}.$$

2.2.5 Recursive Equilibrium

A recursive competitive equilibrium for the economy defined by:

$$\left\{u(c,n^h), \beta, F(k,l), G(m,n), \sigma, \delta, \gamma, H(\epsilon), I(\zeta), z\right\},$$

is a set of functions:

$$\left\{V_0, V_1, W_0, W_1, x_m, n, s', k', l, i, c, n^h, p, q, \omega, D, \Gamma_\mu, \Gamma_\lambda\right\},$$

such that:

1. Given ω, q, p, Γ_μ and Γ_λ, V_0 and V_1 solve the final firm's problem.
2. Given ω, q, p, Γ_μ and Γ_λ, W_0 and W_1 solve the intermediate firm's problem.
3. Given ω, D and p, c satisfies the household's first-order conditions.
4. The final goods market clears:

$$\begin{aligned} c(z,A) = & \int_S \int_0^{\bar{\epsilon}} y(s,\epsilon;z,A) d(H(\epsilon)) d(\mu(s)) \\ & - \int_K \int_0^{\bar{\zeta}} i(k,\zeta;z,A) d(I(\zeta)) d(\lambda(k)). \end{aligned}$$

5. The intermediate goods market clears:

$$\begin{aligned} & \int_S \int_0^{\bar{\epsilon}} x_m(s,\epsilon;z,A) d(H(\epsilon)) d(\mu(s)) = \\ & \int_K \int_0^{\bar{\zeta}} zF(k, n(k,\zeta;z,A)) d(I(\zeta)) d(\lambda(k)). \end{aligned}$$

6. The labor market clears:

$$\begin{aligned} n^h(z,A) = & \int_S \int_0^{\bar{\epsilon}} \left(n(s;z,A) + \epsilon \cdot \mathbf{1}(x_m(s,\epsilon;z,A) \neq 0)\right) d(H(\epsilon)) d(\mu(s)) \\ & + \int_K \int_0^{\bar{\zeta}} (l(k, n(k;z,A)) + \zeta \cdot \mathbf{1}(i(k,\zeta;z,A) \neq 0)) d(I(\zeta)) d(\lambda(k)). \end{aligned}$$

7. The laws of motion for aggregate state variables are consistent with individual decisions and the stochastic processes governing z:

(a) $\Gamma_\mu(z, A)$ defined by $s'(s, \epsilon; z, A)$ and $H(\epsilon)$;

(b) $\Gamma_\lambda(z, A)$ defined by $k'(k, \zeta; z, A)$ and $I(\zeta)$.

2.2.6 Some Terminology

Final Sales (FS), is defined as the total output of the final goods sector. Intermediate goods demand, X, is the total amount of intermediate goods purchased by the final goods sector. Intermediate goods usage, M, is the total amount of intermediate goods used up in production by the final goods sector. The difference between the two evaluated at the relative price of intermediate goods is Net Inventory Investment (NII):

$$\text{NII} = q \times (\text{X} - \text{M}).$$

Total investment is the sum of fixed capital investment and net inventory investment:

$$\text{Total Investment} = \text{Fixed Capital Investment} + \text{NII}.$$

Finally, Gross Domestic Product (GDP) in this physical environment is defined as the sum of final sales and net inventory investment:

$$\text{GDP} = \text{FS} + \text{NII}.$$

3 Calibration and Computation

3.1 Baseline Parameters

The model period is a quarter. We choose the following functional forms for the production functions:

$$F(k, l) = k^{\theta_k} l^{\theta_l},$$
$$G(m, n) = m^{\theta_m} n^{\theta_n}.$$

We discretize the productivity process z into $N_z = 11$ points following Tauchen (1986). The underlying continuous productivity process follows an AR(1) in logarithms with autocorrelation $\rho_z = 0.956$ and an innovation process with standard deviation $\sigma_z = 0.015$.

We set the subjective discount factor, $\beta = 0.984$, the depreciation rate $\delta = 0.017$, and the steady state growth factor $\gamma = 1.004$. A^h is calibrated so that the aggregate labor input equals 0.33. $\theta_m = 0.499$ is calibrated to match the share of intermediate inputs in final output. We set $\theta_k = 0.25$ and $\theta_l = 0.5$, the values used in Bloom (2009), which amounts to a capital elasticity of the firms' revenue function of 0.5[3] and – if we reinterpret the decreasing returns to scale production function in the intermediate goods sector as resulting from monopolistic competition – an implicit markup of 33%. We calibrate θ_n to match an aggregate labor share of 0.64. These parameters are summarized in Table 1:

[3] Cooper and Haltiwanger (2006), using LRD manufacturing data, estimate this parameter to be 0.592; Hennessy and Whited (2005), using Compustat data, find 0.551.

Table 1: Baseline Parameters

β	A^h	θ_m	θ_n	θ_k	θ_l	ρ_z	σ_z	δ	γ
0.984	2.128	0.499	0.367	0.250	0.500	0.956	0.015	0.017	1.004

Notes: β is the subjective discount factor of the households; A^h is the preference parameter for leisure; θ_m is the material share in the final good production function; θ_n is the labor share in the final good production function; θ_k is the capital share in the intermediate good production function; θ_l is the labor share in the intermediate good production function; ρ_z is the auto-correlation for the aggregate productivity process; σ_z is the standard deviation for aggregate productivity innovations; δ is the depreciation rate; γ is the steady state growth rate.

3.2 Inventory and Adjustment Cost Parameters

We assume that the inventory adjustment costs are uniformly distributed on $[0, \bar{\epsilon}]$. $\bar{\epsilon}$ is set so that the average inventory-to-sales ratio in the model equals 0.8185, the average of the real private non-farm inventory-to-sales ratio in the United States between 1960:1 and 2006:4. The unit cost of holding inventories, σ, is chosen so that the annual storage cost for all inventories is 12% of aggregate final output in value (see Richardson (1995) and Khan and Thomas (2007) for details). These two targets jointly determine $\bar{\epsilon} = 0.3900$ and $\sigma = 0.0127$.

We assume that $I(\zeta)$ is uniform between $[0, \bar{\zeta}]$. The upper bound of the distribution is chosen so that the fraction of lumpy investors, defined as the firms whose gross investment rate is larger than 20% in a given year, is 18%. This calibration target is taken from Cooper and Haltiwanger (2006)'s analysis of manufacturing firms in the Longitudinal Research Database (LRD). This yields $\bar{\zeta} = 0.1841$.

3.3 Numerical Solution

The inherent non-linearity of the model suggests global numerical solution methods. We use value function iterations from equation (1) to equation (3) to solve the problem of the final good producers. We use value function iterations from equation (4) to equation (7) to solve the intermediate firm's problem. Howard policy function accelerations are used to speed up convergence.

Our model gives rise to two endogenous distributions as state variables. We adopt the methods in Krusell and Smith (1997), Krusell and Smith (1998), Khan and Thomas (2003) as well as Khan and Thomas (2008) to compute the equilibrium. Denote the Ith moment of distribution $\mu(S)$ and $\lambda(K)$ as $\mu_I(S)$ and $\lambda_I(K)$ respectively. We approximate each distribution function with its first moment. We find that a log-linear form for the $\Gamma(\cdot)$ functions approximates the law of motion rather well in terms of forecasting accuracy:

$$\Gamma_\mu(z, \lambda_1, \mu_1) = \log \mu_1' = \alpha_\mu + \beta_\mu \log(\lambda_1) + \gamma_\mu \log(\mu_1) + \psi_\mu \log(z), \tag{8}$$

$$\Gamma_\lambda(z, \lambda_1, \mu_1) = \log \lambda_1' = \alpha_\lambda + \beta_\lambda \log(\lambda_1) + \gamma_\lambda \log(\mu_1) + \psi_\lambda \log(z). \tag{9}$$

We adopt similar rules for the pricing kernel and the relative price of intermediate goods:[4]

$$\log p = \alpha_p + \beta_p \log(\lambda_1) + \gamma_p \log(\mu_1) + \psi_p \log(z), \tag{10}$$
$$\log q = \alpha_q + \beta_q \log(\lambda_1) + \gamma_q \log(\mu_1) + \psi_q \log(z), \tag{11}$$

where λ_1 is the first moment of the capital stock distribution, and μ_1 is the first moment of the inventory stock distribution.

Given an initial guess for $\{\alpha_{\{\cdot\}}, \beta_{\{\cdot\}}, \gamma_{\{\cdot\}}, \psi_{\{\cdot\}}\}$, we solve the value functions as described above. Then we simulate the model without imposing the pricing rules in equations (10) and (11). In each model simulation period we search for a pair of prices, (p, q) such that all the firms optimize and all the markets clear under the forecasting rules in equation (8) and (9). To improve numerical accuracy, we use the value functions to re-solve all the optimization problems period by period and for every guess of (p, q). Given the market clearing prices, we update the capital and inventory stock distributions and proceed into the next period.

At the end of the simulation, we update the parameters $\{\alpha_{\{\cdot\}}, \beta_{\{\cdot\}}, \gamma_{\{\cdot\}}, \psi_{\{\cdot\}}\}$ using the simulated time series for the approximating moments and the market clearing prices. Then we repeat the algorithm with the updated parameters. Upon convergence of the parameters, we check the accuracy of the $\Gamma(\cdot)$ functions by the R^2 in the regression stage.

4 Results

We study the influence of nonconvex fixed capital adjustment costs on aggregate dynamics in our model by numerical simulation. We analyze four models that share all parameters other than $\bar{\epsilon}$ and $\bar{\zeta}$. 'Model I1' and 'Model I2' have the calibrated baseline equilibrium inventory holdings with $\bar{\epsilon} = 0.39$. 'Model I1' has calibrated fixed capital adjustment cost given by $\bar{\zeta} = 0.1841$, while 'Model I2' features a frictionless technology for adjusting the fixed capital stock. We also simulate two models without inventories, 'Model NI1' and 'Model NI2'. In these models, we set $\bar{\epsilon} = 0$ to eliminate equilibrium inventory holdings.[5] 'Model NI1' has the same level of $\bar{\zeta}$ as 'Model I1', while 'Model NI2' does not feature any frictions in adjusting the fixed capital stock. The parameter specifications for the four models are summarized in Table 2. We do not recalibrate $\bar{\zeta}$ in 'Model NI1' as the calibration targets are largely insensitive to the changes in equilibrium inventory levels, as shown in the fourth column of Table 2. To understand how the presence of inventories interacts with the effects of nonconvex fixed adjustment costs, we study the cross differences. That is, we contrast the differences between 'Model I1' and 'Model I2' with the differences between 'Model NI1' and 'Model NI2'.

We present four sets of results on those four models. We first compare their unconditional business cycle moments. Second, we study the impulse response functions for fixed capital

[4] We have experimented with other functional forms for the forecasting rules such as adding interaction terms between aggregate productivity and the capital and inventory moments. This did not lead to significant improvements in goodness-of-fit. Our specification performs very well as measured by the R^2 of the equilibrium OLS regressions, which exceeds 0.999 in all specifications.

[5] In theory, zero inventory adjustment costs are not inconsistent with positive inventory holdings as the firms might want to hedge against changes in the relative price of intermediate goods. However, in our simulations no firm holds a positive level of inventories when $\bar{\epsilon} = 0$.

Table 2: Model Specifications

Model Name	$\overline{\zeta}$	$\overline{\epsilon}$	Average Adjustment Cost	Fraction of Lumpy Adjusters	Note
I1	0.1841	0.3900	0.9300%	18.00%	Baseline fixed capital adjustment cost with inventory
I2	0.0000	0.3900	0.0000%	0.000%	Frictionless fixed capital adjustment with inventory
NI1	0.1841	0.0000	0.8900%	18.18%	Baseline fixed capital adjustment cost without inventory
NI2	0.0000	0.0000	0.0000%	0.000%	Frictionless fixed capital adjustment without inventory

Notes: 'Model I1' has the baseline calibrated nonconvex fixed capital adjustment cost parameter and the baseline calibrated inventory order cost parameter. 'Model I2' has zero nonconvex fixed capital adjustment cost and the baseline inventory order cost parameter. 'Model NI1' has the baseline calibrated nonconvex fixed capital adjustment cost parameter and zero inventories. 'Model NI2' has zero nonconvex fixed capital adjustment cost and zero inventories. "Average Adjustment Cost" is the average adjustment cost paid as a fraction of firms' output, conditional on adjustment. "Fraction of Lumpy Adjusters" is the share of lumpy adjusters, defined as the firms that adjust more than 20% of their initial capital stocks in a given year, in all firms.

investment and consumption across the four models. Third, we plot the volatility and persistence for consumption, fixed capital investment and, for the models with inventories, net inventory investment for a wider range of $\overline{\zeta}$. And finally, we analyze the role of general equilibrium price movements in bringing about our results.

4.1 Unconditional Business Cycle Analysis

After computing the equilibrium, we simulate the model for 1,000 periods, of which we discard the first 100 to eliminate the influence of initial conditions. Except for net inventory investment, fixed capital investment and total investment, all the simulated time series are transformed by natural logarithms and then detrended by an HP filter with smoothing parameter 1600. The investment data series are treated differently, because they can potentially take on negative values. We detrend fixed capital investment and total investment with the HP filter directly and then divide the deviations by the trend. We first divide net inventory investment by GDP and then apply the HP filter to this ratio.

Table 3: Business Cycle Statistics

(a) Standard Deviation

	GDP	Consumption	Fixed Investment	NII	Total Investment	Inventory Level
Model I1	1.4975	0.6416	9.6619	0.3793	15.0558	1.2204
Model I2	1.5637	0.6336	11.5762	0.3240	16.4462	1.1404
Model NI1	1.4772	0.7624	11.7371	-	11.7371	-
Model NI2	1.5694	0.7436	13.8684	-	13.8684	-
Data	1.6630	0.9015	4.8903	0.4220	8.0616	1.6552

(b) First Order Auto-correlation

	GDP	Consumption	Fixed Investment	NII	Total Investment	Inventory Level
Model I1	0.6833	0.7623	0.7298	0.6157	0.6659	0.9259
Model I2	0.6646	0.7932	0.6110	0.6616	0.6274	0.9379
Model NI1	0.6839	0.7281	0.6648	-	0.6648	-
Model NI2	0.6685	0.7739	0.6251	-	0.6251	-
Data	0.8422	0.8833	0.9006	0.3696	0.6514	0.8908

Notes: "NII" denotes net inventory investment. GDP, consumption, and inventory levels are logged and detrended with an HP filter with a penalty parameter of 1600. We detrend fixed investment and total investment with the HP filter and then divide the deviations by the trend. We divide NII by GDP and then detrend this ratio with the HP filter. All the standard deviations reported in Panel (a) are percentage points.

The business cycle statistics in Panel (a) and (b) of Table 3 show several effects of inventories on aggregate dynamics. The first message is that nonconvex fixed capital adjustment costs matter for aggregate dynamics. Business cycle dynamics differ significantly between 'Model I1' and 'Model I2'. For example, the percentage standard deviation of fixed capital investment decreases from 11.58 in the frictionless 'Model I2' to 9.66 in the lumpy investment 'Model I1'. Persistence of fixed capital investment increases from 0.61 to 0.73. In contrast, consumption volatility and persistence do not vary as much with the fixed capital adjustment cost parameter. Consumption dynamics are largely insulated from variations in capital adjustment frictions in the presence of inventories.[6]

Regarding the cross differences, the effects of nonconvex fixed capital adjustment costs change significantly in models where inventories are absent. Most notably, the persistence of fixed investment only increases by 0.04 between 'Model NI2' and 'Model NI1', while it increases by 0.12 between 'Model I2' and 'Model I1'. The volatility of consumption increases by 0.0188 percentage points between 'Model NI2' and 'Model NI1' while it only increases by 0.0080 percentage points between 'Model I2' and 'Model I1'. These results suggest that inventories strengthen the dampening and propagation effect of fixed adjustment costs on fixed capital investments.[7] At the same time, inventories enhance the households' ability to smooth consumption, making fixed capital adjustment costs much less effective in affecting consumption volatility.

As for net inventory investment and the level of inventories, we see that they behave exactly the opposite way from fixed capital investment, when the latter is subject to adjustment frictions. Their volatility rises and their persistence falls, when capital adjustment frictions are introduced. This is due to the substitution towards inventories as a means of saving, as fixed capital becomes more costly to use.

4.2 Conditional Business Cycle Analysis - Impulse Response Functions

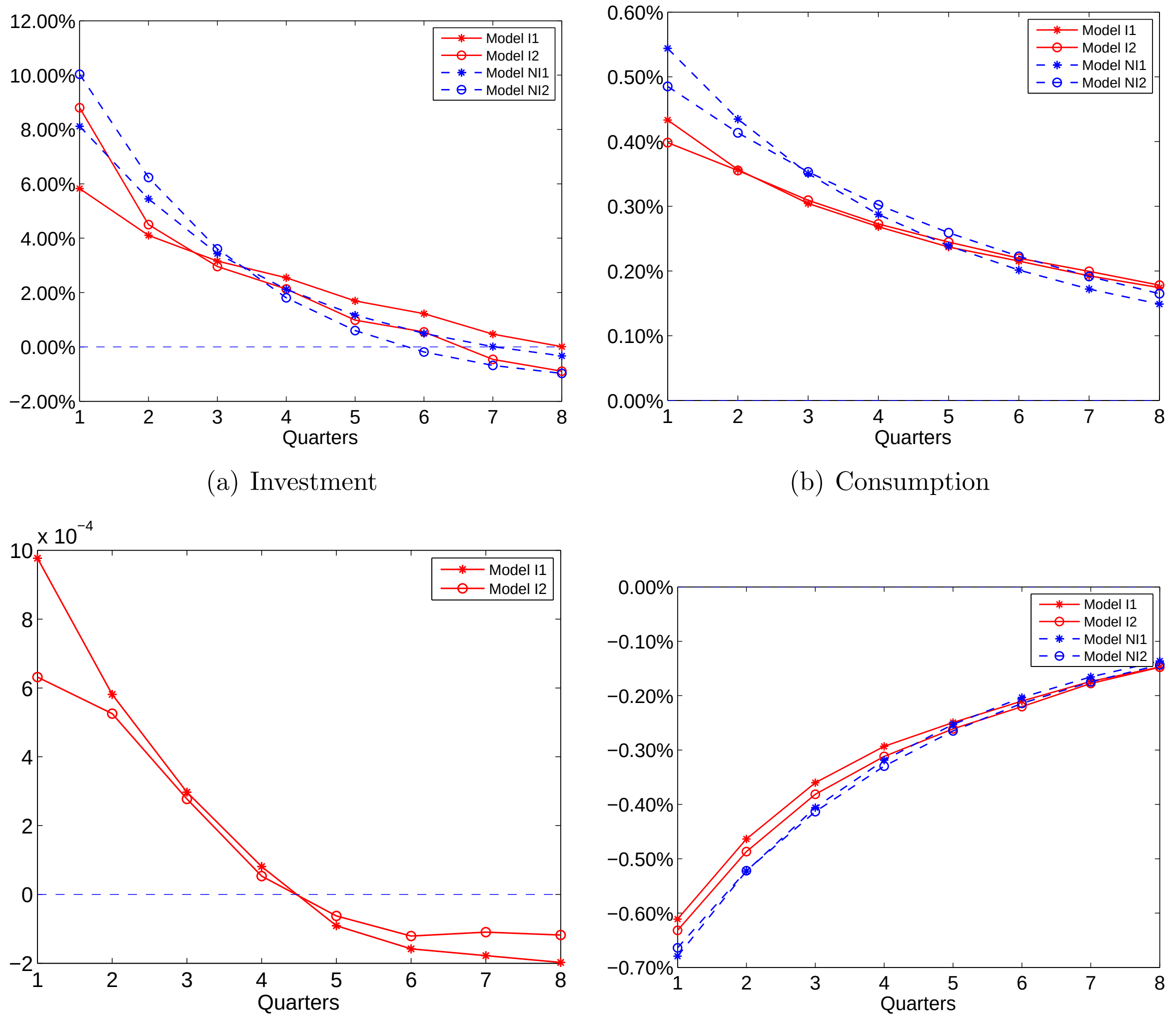
The first two panels of Figure 2 show the impulse response functions of aggregate fixed capital investment and consumption to a positive productivity shock in the intermediate goods sector. We simulate a shock process that starts with one standard deviation above the median level of productivity, $z = 1$, and falls back to unity at the rate of $\rho_z = 0.956$.

Fixed Capital Investment Panel(a) of Figure 2 presents the four impulse response functions for fixed capital investment. Comparing the models with $\overline{\zeta} = 0.1841$ against the models with $\overline{\zeta} = 0$ at the same level of inventories, we can see that nonconvex fixed capital adjustment costs dampen the initial responses both with and without inventories. However, at different levels of inventories, capital adjustment costs dampen these responses to a different degree. Without inventories, the initial response is dampened by 1.91 percentage points. In

[6]The excessively high fixed investment volatility, as shown in the third column of Panel (a), is a common property of two-sector models where fixed capital is only used in intermediate goods production. Khan and Thomas (2007) find similar results. As fixed adjustment cost works to dampen investment volatility, this might point to our calibration of $\overline{\zeta}$ being conservative.

[7]Note that already without inventories we have that nonconvex fixed capital adjustment costs matter somewhat for aggregate dynamics as our revenue elasticity of capital is lower than in the Khan and Thomas calibrations; see Gourio and Kashyap (2007) for this insight.

Figure 2: Impulse Response Functions



(a) Investment

(b) Consumption

(c) Net Inventory Investment

(d) Relative Price

Notes: This figure shows the impulse response functions of fixed capital investment, consumption, net inventory investment(NII) and the relative price to a one standard deviation aggregate productivity shock in the intermediate goods sector. 'Model I1' has the baseline calibrated nonconvex fixed capital adjustment cost parameter and the baseline calibrated inventory level. 'Model I2' has zero nonconvex fixed capital adjustment cost and the baseline calibrated inventory level. 'Model NI1' has the baseline calibrated nonconvex fixed capital adjustment cost parameter and zero inventories. 'Model NI2' has zero nonconvex fixed capital adjustment cost and zero inventories. The impulse response of net inventory investment is reported in absolute values, instead of percentage points, as the steady state value of net inventory investment is zero.

contrast, the initial response is dampened by 2.99 percentage points in models with inventories. Inventories also increase shock propagation. Comparing the impulse response function of 'Model I1' with that of 'Model NI1' without inventories, we see that the impulse response function in the model with inventories is flatter.

Both the extra dampening effect and the increased propagation of the shocks come from the key mechanism in our model: the substitution between fixed capital investment and inventory investment as a means of saving. When adjusting fixed capital is costly, the economy switches to inventories for saving. As a result, fixed capital investments do not need to respond to productivity shocks as much as when inventories are absent. The responses are also more protracted because firms tend to wait for lower adjustment cost draws to invest.

The flip side of the substitution between two saving channels can be observed in Panel(c) of Figure 2, which shows the impulse response functions of net inventory investment. As expected, the response of net inventory investment is much stronger when adjusting fixed capital investment is costly. In 'Model I1', the impact response is 0.00098, while in 'Model I2' it is only 0.00063.[8]

The same mechanism can also explain the other cross effect, namely how lumpy fixed capital investment changes the effect of inventories on aggregate investment dynamics. For both levels of fixed capital capital adjustment costs, inventories dampen the positive response of fixed capital investment to a positive productivity shock, as the latter is no longer used as much to ensure consumption smoothing. This switching away from fixed capital investment as a means of saving is stronger, the more costly it is to use, i.e. when fixed capital adjustment frictions are present. This explains why inventories dampen the initial response of fixed capital investment by somewhat over 2 percentage points with fixed capital adjustment frictions, but only by 1 percentage point, when fixed capital can be freely adjusted.

Consumption Another implication from the above mechanism is that consumers' ability to smooth consumption is enhanced by inventories. We illustrate this with the impulse response functions for consumption in Panel(b) of Figure 2.

First, the impact response from the models with inventories is below those from the models without inventories, for every level of fixed capital adjustment costs. Secondly, the smoothing effectiveness of inventories is so good that consumers despite the presence of capital adjustment costs can almost exactly recreate their frictionless consumption path. Nonconvex fixed capital adjustment costs barely change the response of consumption after the initial impact, if consumers can save in inventories. In contrast, without inventories nonconvex fixed capital adjustment costs do interfere with consumption smoothing.

We interpret these response functions as evidence that inventories provide an effective smoothing device for the consumers. As a result, consumption dynamics are less volatile when productivity shocks hit and capital adjustment frictions are less relevant for consumption dynamics in the presence of inventories.

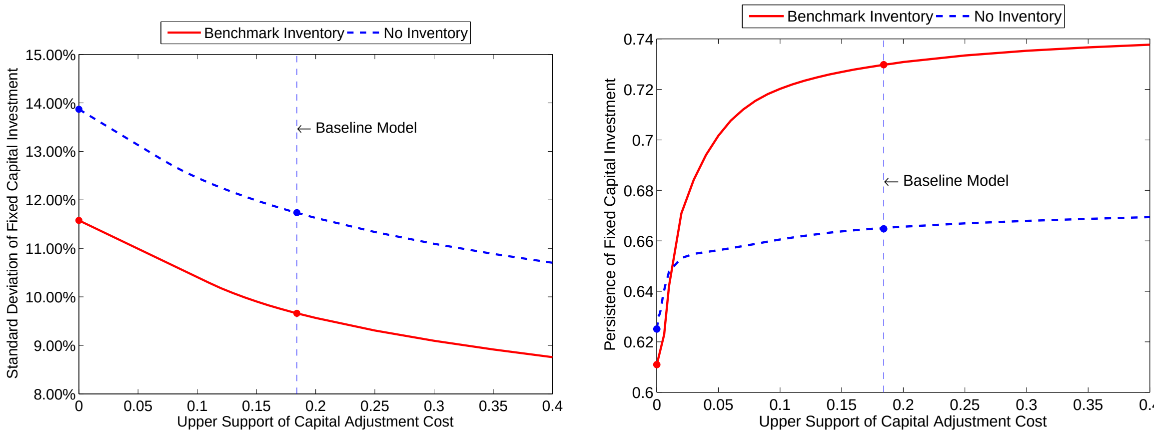
4.3 Volatility and Persistence as a Function of Capital Adjustment Costs

In this section we illustrate the saving vehicle substitution mechanism from a slightly different angle. We now simulate our model under our calibrated inventory level and the "No Inventory" setup over a wide range of $\overline{\zeta} \in [0, 0.4]$. The lower bound is frictionless adjustment, whereas the upper bound, 0.4, is approximately twice our baseline $\overline{\zeta} = 0.1841$.[9] We study how the volatility and persistence statistics of fixed capital investment, consumption and net inventory investment change over this range of fixed capital adjustment costs.

[8] The impulse responses for NII are reported in absolute changes, not in percentage changes relative to the steady state. This is because the steady state value for NII is zero.

[9] At $\overline{\zeta} = 0.4$ the annual fraction of firms which have lumpy investments is 15.23%, and the annual average adjustment cost paid conditional on adjustment and measured as a fraction of the firm's output is 1.66%.

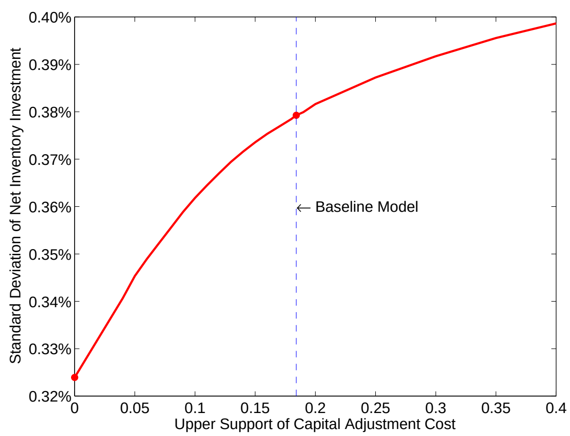
Figure 3: Volatility and Persistence of Fixed Capital Investment



(a) Volatility (b) Persistence

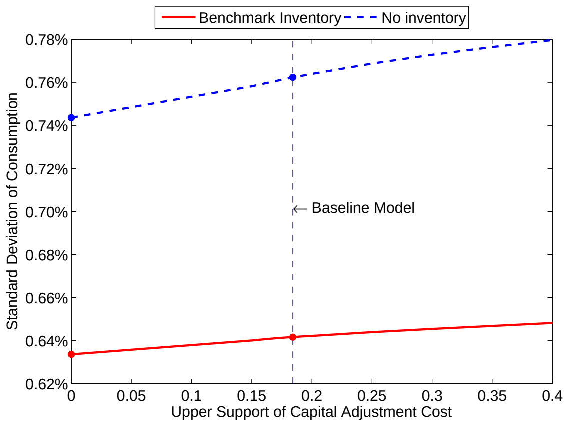
Notes: This figure shows the volatility and persistence of fixed capital investment for models with $\bar{\zeta} \in [0, 0.4]$. The x-axis for both panels shows the upper bound of the capital adjustment cost distribution, $\bar{\zeta}$. In Panel(a), the y-axis shows the percentage standard deviation of fixed capital investment. In Panel(b), the y-axis shows the first-order auto-correlation of fixed capital investment. We detrend fixed capital investment with the HP(1600) filter and then divide the deviations by the trend.

Figure 4: Volatility of Net Inventory Investment

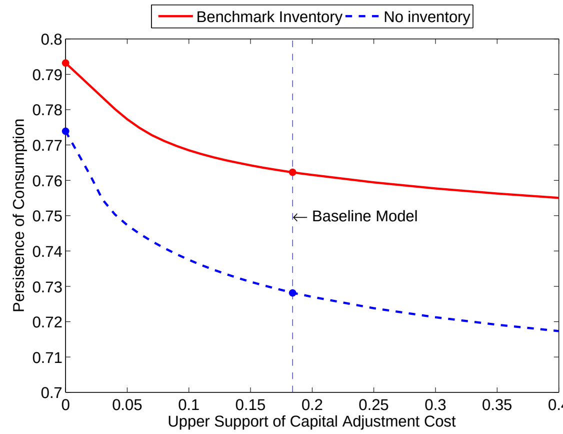


Notes: See notes to Figure 3. This figure shows the volatility of net inventory investment (NII) for models with $\bar{\zeta} \in [0, 0.4]$. We divide NII by GDP and then detrend this ratio with the HP filter.

Figure 5: Volatility and Persistence of Consumption



(a) Volatility



(b) Persistence

Notes: See notes to Figure 3. This figure shows the volatility and persistence of aggregate consumption for models with $\overline{\zeta} \in [0, 0.4]$. Consumption is logged and detrended with an HP filter with a smoothing parameter of 1600.

Panel (a) of Figure 3 presents the volatility of fixed capital investment over said $\overline{\zeta}$-range for both the baseline inventory model and the "No Inventory" model. Independently of the level of inventories, higher capital adjustment costs dampen the volatility of fixed capital investment. The interaction between inventories and nonconvex capital adjustment costs are most apparent in the persistence of fixed capital investment in Panel (b) of Figure 3. With inventories, persistence increases from 0.61 to 0.74 when $\overline{\zeta}$ changes from 0 to 0.4. In contrast, without inventories the persistence only increases from 0.62 to 0.67 over the same range of $\overline{\zeta}$. The agents rely less on fixed capital investment when inventories are available. As a result, the fluctuations in fixed capital investments are dampened and stretched.

We can directly observe the substitution between different saving channels by comparing the volatility of fixed capital investment in Figure 3 to the volatility of net inventory investment in Figure 4. As fixed adjustment costs get higher, the agents rely more on inventories and less on fixed capital to save. As a result, higher fixed adjustment costs lead to more volatile net inventory investment and less volatile fixed capital investment. The standard deviation of net inventory investment *increases* from 0.32% when $\overline{\zeta} = 0$ to 0.40% when $\overline{\zeta} = 0.40$. Over the same range of $\overline{\zeta}$, the standard deviation of fixed capital investment *decreases* from 11.6% to 8.8%.

Also, we can see the implications of the saving substitution mechanism in the dynamics of consumption. Figure 5 shows that with inventories the volatility of consumption is lower for every level of capital adjustment costs. More importantly, as the slopes of the two curves suggest, the rate at which fixed adjustment costs increases consumption volatility is lower when inventories exist. In other words, the same increase in fixed adjustment cost forces consumption volatility to move up higher when inventories are absent from the economy, whereas it can barely increase consumption volatility when inventories are present.

The change in consumption persistence reveals the same mechanism, as shown in Panel (b) of Figure 5. The existence of inventories changes the degree to which fixed capital adjustment costs affect consumption persistence. Over the same range of $\overline{\zeta}$, consumption persistence decreases by much less in the inventory models compared to the "No Inventory" models.

4.4 The Effect of Market Clearing

The results on the effectiveness of fixed capital adjustment costs with or without inventories so far take into account all general equilibrium (GE) effects, i.e. adjustments of real interest rates and real wages, as well as the relative price of intermediate goods. In this section we isolate the effects of these price movements on how inventories impact the (non)-neutrality of nonconvex fixed capital adjustment costs.

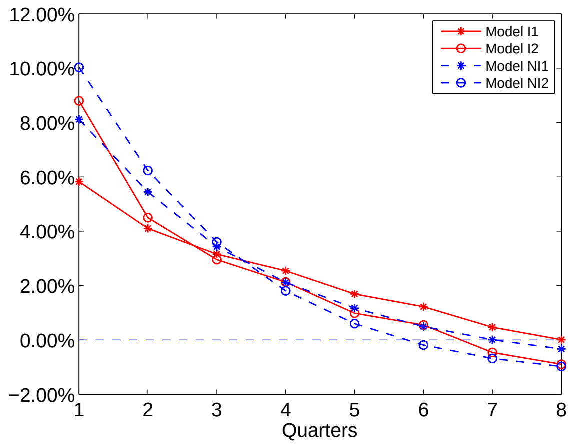
To this end, we solve three partial equilibrium versions of our model. In the first case, we fix both the pricing kernel, p, and the relative price q, at their long-run general equilibrium averages and simulate the model. In the second case, we fix the pricing kernel (and thus the real wage) to its long-run general equilibrium average, but allow the relative price to adjust so that the intermediate goods market clears. In the last case we fix the relative price to its long-run general equilibrium average, but allow the pricing kernel (and the real wage) to adjust so that the final goods market clears.

The impulse response functions of fixed capital investment for all three cases are reported next to the full general equilibrium case – Panel (a) – in Figure 6. Panel(b) is the response from the first partial equilibrium case where both prices are fixed. Two messages emerge from this case. First, as is well known in the literature, nonconvex adjustment frictions matter a lot in partial equilibrium: the impact response drops massively and propagation arises only when fixed adjustment frictions are introduced. Second, inventories by and large do not change the effect of fixed adjustment frictions, as the differences between Model I1 and I2 are very similar to the differences between Model NI1 and NI2. Put differently, the effect of fixed capital adjustment frictions swamps the differential effect of inventories.

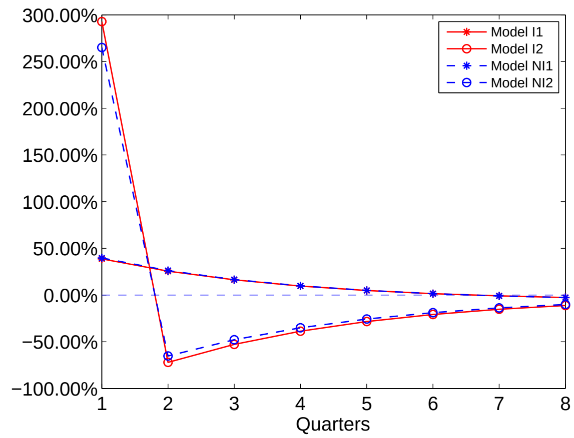
Panel(c) presents the response functions from the models where the pricing kernel is fixed but the relative price is not. The results in these models are very similar to those in the first case where both prices are fixed. Once again, nonconvex adjustment frictions matter a lot, but inventories do not interact with them significantly. Market clearing in the intermediate goods market only leads to slightly dampened fixed investment responses overall, as decreases in the relative price q (see Panel(d) of Figure 2) lead saving and investment activities away from fixed capital investment. .

In other words, our exercise of comparing differences in differences really becomes only interesting, once real interest rate and real wage movements have been taken into account. The response functions in Panel(d) of Figure 6 come from the models where the pricing kernel and the real wage move freely to clear the final goods market, yet the relative price of intermediate goods is fixed. These response functions closely resemble those from the general equilibrium case. In models with inventories, the impact response of fixed investment is 40% higher with frictionless fixed capital adjustment, in models without inventories it is only 26% higher. Nevertheless, market clearing in the intermediate goods market does play a role in rendering fixed capital adjustment frictions more relevant. Recall that in full general equilibrium the difference in the initial fixed investment response between the frictionless model and the lumpy model was 50% vs. 24%. The decline of the relative price q after an increase in aggregate productivity further facilitates the shifting of saving activities into building up inventories and away from fixed capital investment. This substitution channel, for a given decline in q, is more valuable in an economy, where fixed capital adjustment is costly.

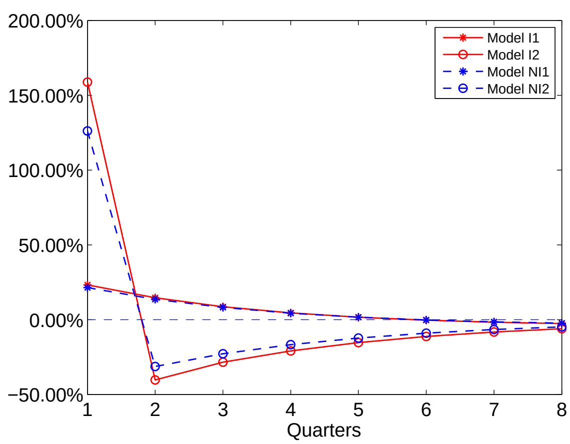
Figure 6: IRF for Fixed Capital Investments in Partial Equilibrium Models



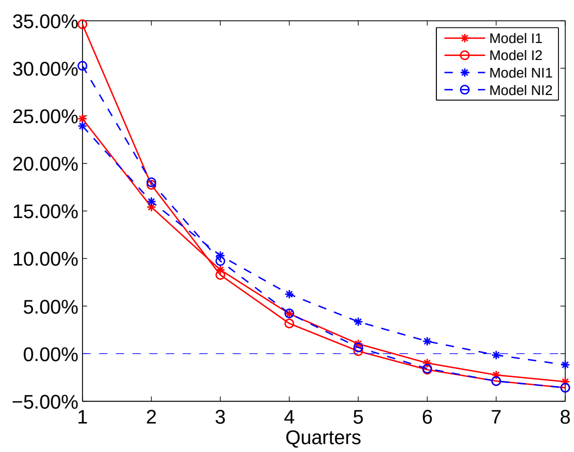
(a) General Equilibrium



(b) PE: Both Prices Fixed



(c) PE: Pricing Kernel Fixed



(d) PE: Relative Price Fixed

Notes: These are the impulse response functions for fixed capital investments. Panel(a) is the reproduction of Figure 1. Panel(b) is based on models where both the pricing kernel and the relative price are fixed. Panel(c) is based on models where only the pricing kernel is fixed. Panel(d) is based on models where only the relative price is fixed.

5 Conclusion

This paper shows that it matters for the aggregate implications of microfrictions *how* general equilibrium effects are introduced into the physical environment of dynamic stochastic general equilibrium models with these microfrictions. Specifically, we show that how relevant nonconvex fixed capital adjustment costs are for business cycle dynamics depends on how the aggregate resource constraint is modeled, depends on how the model is closed.

We develop a dynamic stochastic general equilibrium model to evaluate how the availability of multiple saving channels, here inventories in addition to fixed capital, affects the aggregate implications of nonconvex capital adjustment costs. We find that with more than one ways of saving, capital adjustment costs are more effective in dampening and propagating the response of fixed capital investment to an aggregate productivity shock.

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