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Credit constraints, firms' precautionary investment, and the business cycle

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A B S T R A C T

Credit constrained firms prefer types of capital that generate significant pledgeable output and are liquid, since they loosen current and future credit constraints. Because pledgeability and liquidity are low for long-term firm-specific capital, a negative temporary aggregate productivity shock that tightens credit constraints creates a bias towards liquid short-term investments. This dampens the short-run negative output reaction to the shock, at the expense of strong medium-run propagation effects. This mechanism can create a short-run expansion when a future tightening in credit conditions is anticipated.

1. Introduction

How do financial constraints of firms affect the dynamics of the aggregate composition of investment? And how does the behavior of the composition of investment in the presence of financing constraints influence the response of an economy to shocks?

This paper focuses on the distinction between investment in liquid and illiquid capital. Capital is liquid when it can be resold easily, or when it generates most of its output in the short run. Examples include inventory, machinery and equipment, and commercial or industrial structures with a high resale value. Capital is illiquid when it generates most of its output in the long run and cannot be resold easily in the short run, such as research and development (R&D), firm-specific structures, firm-specific human capital, firm branding, and growth options. Firm-level empirical work has found that financially constrained firms are more likely to invest in short-term, redeployable and tangible capital.[1] Work starting with Rajan and Zingales (1998) has shown that industries with a long duration of investment projects grow less in poorly developed financial systems and tend to do worse in recessions (Braun and Larrain, 2005). At the aggregate level, the average maturity of aggregate investment falls in downturns (Dew-Becker, 2012), and particularly so in less financially

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[1] Credit constrained firms are more likely to increase price markups at the expense of longer-term market share building (Chevalier and Scharfstein, 1996), prefer investment projects that deliver cash flows earlier (Peyer and Shivdasani, 2001), display a more procyclical pattern of their share of R&D investment (Aghion et al., 2012), and tend to purchase used, rather than new, capital, with a more front-loaded pattern of cash flows (Eisfeldt and Rampini, 2007). Brown et al. (2009) and Gatchev et al. (2009) show that firms finance most of their R&D expenditures, marketing expenses and product development internally out of retained earnings. Investment in commercial real estate, instead, is primarily financed with mortgage loans, and the amount of external finance it attracts increases with its redeployability (Benmelech et al., 2005).

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developed economies (Aghion et al., 2010). Taken together, this evidence is consistent with a preference of financially constrained firms for liquid capital.

We develop a model that delivers firm policies consistent with this evidence and use it to address several questions. Does the ability of firms to choose the liquidity of their investment projects interact with financing constraints and idiosyncratic firm risk to dampen or amplify the short-run effects of aggregate productivity shocks? Does it influence how the effects of productivity shocks propagate through time? How does it influence the impact of financial shocks? To answer these questions we introduce a dynamic general equilibrium model of an economy in which heterogeneous firms produce a homogeneous final good using two decreasing returns to scale technologies, which they can operate simultaneously. The liquid technology produces cash-flows only in the short-run, and is meant to capture investments that either generate most of their cash-flows early, or that can be resold easily in the short run. The illiquid technology produces most of its output in the long run, and uses capital that depreciates slowly and can only be resold at a large discount because of its firm specificity. Firm heterogeneity arises from idiosyncratic operating cost shocks, and firms face the possibility every period of being forced to exit the economy. External finance is restricted to riskless debt, and firms can only pledge a fraction of their future earnings. As a result, they optimally accumulate units of the final good as a buffer against problems in obtaining credit in the future.

Credit constraints create a preference for liquid investments through two mechanisms. First, because debt is restricted to be riskless and because the firm might not exist in the period after next, only cash-flows that occur next period are pledgeable to lenders. As a result, firms with a currently binding credit constraint prefer liquid capital because it produces relatively more pledgeable output and can attract more external finance. Second, the anticipation of future credit constraints also creates a bias towards liquid investment. Illiquid capital runs the risk of having to be liquidated at a cost in the future if the firm is in financial distress after suffering several negative idiosyncratic operating cost shocks, and this causes illiquid capital to have a lower expected return for firms with low net worth. This precautionary behavior is in line with evidence that the expectation of future financing constraints has important implications for current firm behavior.[2]

Next, we describe and quantify a novel mechanism that delivers short-run dampening of productivity shocks and long-run propagation. In an economy with frictionless credit markets, following a negative temporary aggregate productivity shock, firms decrease their liquid investment, which offers poor returns in downturns, but barely alter their illiquid investment, whose returns are less cyclical because they occur mostly in the long run. Output contracts sharply but recovers quickly. In an economy that features credit constraints, the decrease in profits and net worth increases the share of firms with binding credit constraints. Firms' net worth recovers slowly so credit constraints are expected to remain tight for some time. Because of the currently binding credit constraints and the anticipation of future constraints, many firms are unable or unwilling to sustain previous levels of illiquid investment and instead increase the share of their investment allocated to liquid capital. This shift to liquid projects increases the production of goods in the short run and dampens the short run output fall. Over the first five quarters, the output fall is smaller in the financially constrained economy by an accumulated amount equivalent to 2.3% of quarterly steady state output. However, the large drop in illiquid investment generates significant propagation effects. Convex costs of adjustment in investment and the slow recovery of firms' balance sheet strength mean that the large initial fall in the stock of illiquid capital takes a long time to recover and over the subsequent thirty-five quarters the output fall in the financially constrained economy is greater than in the unconstrained economy by an accumulated amount equivalent to 6.9% of quarterly steady state output. As a result, a trade-off arises between contemporaneous amplification and long-term propagation of the effects of shocks; stronger dampening is associated with more propagation. Our results about the aggregate dynamics of the composition of investment contribute to a large theoretical literature starting with Bernanke and Gertler (1989) and Kiyotaki and Moore (1997) that studies how aggregate investment responds to shocks in the presence of financing constraints, and to a small literature that studies how distortions in the composition of investment caused by financing constraints may affect long-run growth (Acemoglu and Zilibotti, 1997; Matsuyama, 2007; Aghion et al., 2010).

Our analysis also delivers other insights. First, it introduces a novel explanation for the countercyclicality of financing constraints. The incentive to shift towards illiquid projects in recessions because their returns are relatively acyclical decreases the amount of pledgeable output for a given level of total investment, and makes it more likely that credit constraints bind and that firms' capital mix moves away from its unconstrained optimum in recessions. Second, our analysis highlights the important role that idiosyncratic risk plays for our results. Decreasing the volatility of these shocks reduces the strength of the contemporaneous dampening and intertemporal propagation of productivity shocks.

Highlighting the role of firms' precautionary behavior in anticipation of future credit constraints, news of a future financial shock can generate a short-run boom in the economy. Firms' precautionary behavior in reaction to the news that their financing constraints will be tighter in the future induces a shift into the liquid investment, which raises current output, at the expense of a fall in illiquid investment that generates large future decreases in output.

We also study the impact of investment tax credits given their direct relationship with the distortions presented in this paper. Cyclical expensing allowances that allow for larger tax credits in downturns have an important impact on the

[2] Surveys by Graham and Harvey (2001) and Bancel and Mittoo (2004) find that Chief Financial Officers consider having enough internal funds to avoid having to forego positive net present value projects in the future to be the primary determinant of their policy decisions. Almeida et al. (2011) and Caggese and Cuñat (2008) provide evidence that shows that the expectation of future financing problems significantly affects firms' current investment and hiring policies.

dynamics of the composition of investment following a productivity shock, and generate a reduction in short-run output and an increase in medium and long-run output, relative to the benchmark calibration absent cyclical expensing allowances. This result points towards one of the key policy implications of the frictions modeled in this paper, which is that policies that are targeted towards eliminating distortions that hamper illiquid investment should be evaluated in the long term, as they might come at the cost of a drop in short-run output.

Taken together, our results suggest that firms' investment liquidity choice is an important ingredient in models that try to analyze the influence of financial frictions in firms for short-run macroeconomic dynamics.

The remainder of the paper is organized as follows. Section 2 introduces the model. Section 3 discusses the calibration of the model and analyzes firms' optimal decisions in the steady state. Section 4 presents the main results of the model concerning the reaction of the economy to productivity and financial shocks. Section 5 analyzes the role of idiosyncratic firm uncertainty and investment tax credits, and Section 6 concludes.

2. Model

We introduce an infinite horizon, discrete time model of an economy populated by a continuum of financially unconstrained households and a continuum of financially constrained firms, both of measure one. Households own the firms and provide labor to them. Firms combine labor and capital, which can be liquid or illiquid, to produce a homogenous final good that can be used for consumption and investment. They face idiosyncratic risk and as a result are heterogeneous in terms of their net worth and of their holdings of illiquid capital. A government collects corporate income taxes from the firms and distributes the revenues to households with a lump-sum transfer. We begin our description of the economy by studying the optimization problem faced by firms, then follow with a discussion of households' optimization and the competitive equilibrium.

2.1. Firms

Firms maximize the present value of expected future dividends paid out to the households. We discuss next their production opportunities, financing choices, life cycle, and optimization problem.

2.1.1. Production opportunities

Firms can simultaneously operate two different technologies to produce the final consumption good. Each production process uses capital $k_{h,t+1}$ invested in period t and labor $l_{h,t}$ to produce an amount of final goods $f_{h,t+1}(k_{h,t+1}, l_{h,t})$ in period $t+1$, according to the production function

$$f_{h,t+1}(k_{h,t+1}, l_{h,t}) = \theta_{h,t+1} k_{h,t+1}^{\alpha_h} l_{h,t}^{\gamma_h}, \tag{1}$$

where $h \in \{L = \text{liquid}, I = \text{illiquid}\}$ refers to the type of technology, and $\theta_{h,t+1}$ is an aggregate productivity term given by

$$\theta_{h,t+1} = \theta_h \theta_{t+1}, \tag{2}$$

in which θ_h is a constant productivity parameter of the technology type h and θ_{t+1} is an aggregate productivity factor common to both liquid and illiquid production technologies.[3] The production functions feature decreasing returns to scale, captured by $\alpha_h + \gamma_h < 1$. Total output produced by the firm is

$$y_{t+1} = f_{L,t+1}(k_{L,t+1}, l_{L,t}) + f_{I,t+1}(k_{I,t+1}, l_{I,t}). \tag{3}$$

The liquid technology produces all of its output in period $t+1$, something which is captured by a full depreciation of liquid capital $k_{L,t+1}$ within one period. The illiquid technology instead produces output over multiple periods, driven by a gradual depreciation of illiquid capital $k_{I,t+1}$ at rate δ, where $0 < \delta < 1$. Furthermore, illiquid capital is firm-specific and partially irreversible. A firm can convert undepreciated illiquid capital back into the final good, but will only obtain π units ($0 < \pi < 1$) of the final good per unit of terminated illiquid capital in return. Our modeling of illiquid capital captures investments to which the firm is tied to for a long period of time, and can only undo at a cost. If illiquid capital could be redeployed productively in other firms and as a result had a liquid secondary market, it would not be perceived as a long-term investment by the firm as it could undo such an investment at any time at a very low cost. Finally, $\theta_L > \theta_I$, which means that a given level of investment in liquid capital delivers higher per-period output than an identical amount of illiquid investment. All of these differences in combination are meant to capture the notion that the liquid investment provides a front-loaded pattern of cash-flows, whereas the illiquid investment delivers a back-loaded one.

Accumulation of illiquid capital follows the rule

$$k_{I,t+1} = (1-\delta) k_{I,t} + i_{I,t}, \tag{4}$$

[3] We use time subscript $t+1$ for capital installed in time t that delivers output in period $t+1$, and time subscript t for labor input used during period t in the same production process that delivers output in period $t+1$. Labor input is required only during the production process phase in period t, and wages have to be paid in period t, as will be discussed later.

where $i_{I,t}$ represents period t investment in illiquid capital. Positive investment in illiquid capital suffers from convex costs of adjustment according to the function $\psi(i_{I,t})$, which satisfies $\psi(i_{I,t} \leq 0) = 0$, $\psi'(i_{I,t} \geq 0) > 0$ and $\psi''(i_{I,t} \geq 0) > 0$.

Firms face the possibility of suffering an idiosyncratic operating cost shock s_t each period with probability p. The size of this shock is proportional to the size of the firm's operations, measured as the total capital stock of the firm, so that

$$s_t = \varepsilon\left(k_{L,t+1} + k_{I,t+1}\right), \tag{5}$$

where $\varepsilon > 0$. The occurrence of the shock, which happens in the middle of a period after investment is done but before output is produced, is captured by the indicator function 1_s, which takes value 1 if the shock occurs, and value 0 if it does not. The additive nature of these shocks is meant to capture that these are not shocks to output, but rather direct shocks to firms' operating income capturing unexpected operating expenditures, such as higher capital maintenance or input costs. As a result of this shock, profits can be negative and firms need to hold enough liquidity to be able to withstand the operating cost shock if it occurs. If the shock is not paid, the project terminates and yields nothing (not even the liquidation value of illiquid capital). The modeling of these shocks follows the model of corporate liquidity demand of Holmstrom and Tirole (1998). As we will see, idiosyncratic risk is an important ingredient in our results, and considering other sources of risk such as firm-level productivity shocks does not affect the key results of the paper.

2.1.2. Firms' flow of funds

Firms need to finance wages and investment, including adjustment costs of investment. They can do so by using retained earnings, the proceeds from liquidating illiquid capital, or by borrowing. Firms are able to borrow an amount b_{t+1} (or save an amount $-b_{t+1}$) using one-period debt contracts at the equilibrium riskless interest rate $1 + r_{t+1}$.

A firm's holdings of the final good, also referred to as "asset holdings" or "asset position", computed at the beginning of a period is denoted $a_{f,t}$, and the dynamics of $a_{f,t}$ are given by

$$a_{f,t+1} = y_{t+1} - 1_s s_t - b_{t+1}(1 + r_{t+1}) - tax_{t+1}, \tag{6}$$

where borrowing b_{t+1}, if $i_{I,t} \geq 0$, is given by

$$b_{t+1} = i_{I,t} + \psi(i_{I,t}) + k_{L,t+1} + w_t(l_{L,t} + l_{I,t}) + d_t - a_{f,t}, \tag{7}$$

or, if $i_{I,t} < 0$, is given instead by

$$b_{t+1} = \pi i_{I,t} + k_{L,t+1} + w_t(l_{L,t} + l_{I,t}) - a_{f,t}, \tag{8}$$

and where tax_t are corporate taxes, which are a result of a flat rate τ over positive taxable profits, so that, if $i_{I,t-1} \geq 0$,

$$tax_t = \tau\left[y_t - 1_s s_{t-1} - k_{L,t} - \delta k_{I,t} - r_t b_t - \psi\left(i_{I,t-1}\right) - w_{t-1}(l_{L,t-1} + l_{I,t-1})\right], \tag{9}$$

or, if $i_{I,t-1} < 0$,

$$tax_t = \tau\left[y_t - 1_s s_{t-1} - k_{L,t} - \delta k_{I,t} - r_t b_t + (\pi - 1)(-i_{I,t-1}) - w_{t-1}(l_{L,t-1} + l_{I,t-1})\right]. \tag{10}$$

Taxable profits in expression (9) include revenues net of allowed expenses (the operating cost shock, adjustment costs of investment when there is positive investment, depreciation of capital, and wages), minus (plus) interest expense (interest income). When there is some liquidation of illiquid capital, the proceeds from disinvestment are treated as revenues for tax purposes (expression (10)), net of the book value of the liquidated capital. There is an asymmetry at zero profits, and firms pay no taxes if profits are negative. The benchmark version of the model does not consider investment tax credits, such as additional deduction allowances for capital depreciation or additional investment expensing allowances. This is done in Section 5.2, which studies how tax policies can be used to deal with the distortions discussed in this paper.

We denote with $a^-_{f,t+1}$ the asset position at the beginning of period $t+1$ if the operating cost shock occurred ($1_s = 1$) during period t, and conversely with $a^+_{f,t+1}$ the asset position in the case it did not ($1_s = 0$).

2.1.3. Firm entry and exit

Firms face an exogenous exit shock that occurs with probability η, which can be interpreted as a permanent negative idiosyncratic productivity shock that forces firms to exit. Firms distribute all of their asset holdings $a_{f,t}$ plus the liquidation value of their undepreciated illiquid capital $\pi(1-\delta)k_{I,t}$ as dividends before exiting. A firm that exits is immediately replaced by a new firm with no assets or illiquid capital, which means that firms are created homogeneous but become endogenously heterogeneous through the effect of the idiosyncratic operating cost shock.

2.1.4. Financing frictions

Firms face financing constraints that limit their ability to obtain external finance using both debt and equity. Firms are unable to obtain any equity finance, which means that their dividends cannot be negative, so

$$d_t \geq 0, \tag{11}$$

and not being able to issue equity also means that firm assets, including the liquidation value of illiquid capital, can never be below zero, or

$$a_{f,t} + \pi(1-\delta)k_{I,t} \geq 0, \tag{12}$$

because, should the firm be forced to exit with a negative asset position, the shareholders would have to contribute additional funds to cover the negative asset position. This would violate constraint (11). One of the implications of this constraint is that a firm might have to liquidate part of its illiquid capital stock ($i_{I,t-1}<0$) if the current investment choices will result in a negative asset position if the cost shock occurs. It follows that the anticipation of future constraints decreases the expected productivity of illiquid capital. We provide further discussion of this idea when we develop it formally in Section 2.4.2.

Firms, on the other hand, are able to obtain debt financing using non-contingent debt, and the amount borrowed is constrained to be no more than a fraction μ_t of the present value of future output. Because only riskless debt is available, promised future debt repayments cannot be larger than the lowest possible realization of all future earnings. The positive probability that firms suffer every period of having to exit means that earnings obtained in periods after $t+1$ cannot be pledged because the firm might not exist after period $t+1$. As a result, firms can only borrow up to a fraction μ_t of the present discounted value of next period's earnings if the firm suffers a shock, plus the liquidation value π of the stock of illiquid capital $(1-\delta)k_{I,t+1}$, so that

$$b_{t+1} \le \mu_t \frac{y_{t+1}-s_t+\pi(1-\delta)k_{I,t+1}}{1+r_{t+1}}. \tag{13}$$

The assumption that only a fraction μ_t of future earnings are pledgeable can be justified, following Hart and Moore (1994) and Kiyotaki and Moore (1997), if one assumes that each project requires the input of the firm manager and that, without her services, revenues are a fraction $(1-\mu_t)$ lower. Then she could threaten to withdraw her services and renegotiate her liability down to a fraction μ_t of revenues. Another justification could be along the lines of Holmstrom and Tirole (1997). One could assume that the borrower has to contribute an unobservable effort to increase the expected return of the project and that, in order for her to have the proper incentives, at least a particular fraction of the expected returns need to accrue to her and cannot be pledged to lenders.[4]

The crucial implication of this borrowing constraint is that illiquid irreversible capital k_I attracts less external finance than liquid capital k_L. If illiquid capital was fully reversible or easily redeployable to a similarly productive use outside the firm, then the firm could effectively pledge the full present value of the future returns from illiquid capital (adjusted for μ_t), and liquid and illiquid capital would both attract the same amount of external finance. The additional assumption of irreversibility and firm-specificity of illiquid capital, however, means that firms instead can only promise the limited liquidation value π of each unit of illiquid capital. The returns of liquid investment, on the other hand, are fully pledgeable, because they all occur in period $t+1$, immediately before the firm is exposed to the risk of exit. We provide further discussion of this idea when we develop it formally in Section 2.4.1.

2.1.5. Firm Optimization

Firms maximize the present discounted value of dividends d_t distributed to their shareholders, the households. There is no aggregate uncertainty and firms take as given the path of future aggregate variables, given by the sequence starting at time t of the interest rate, wage, aggregate productivity and financing constraints $z_t=\{r_s, w_s, \theta_s, \mu_s\}_{s=t}^{s=\infty}$. A firm's individual state variables are its asset holdings $a_{f,t}$ and its stock of illiquid capital $k_{I,t}$. Its value function, calculated at the beginning of period t, conditional on not having suffered the exogenous exit shock and thus being able to operate for another period, is given by

$$\begin{aligned} J(a_{f,t}, k_{I,t}, z_t) = \max_{d_t, k_{L,t+1}, k_{I,t+1}, l_{L,t}, l_{I,t}, b_{t+1}} \; & d_t + M_{t,t+1}\Big[\eta\Big(p a^-_{f,t+1} + (1-p) a^+_{f,t+1} + \pi(1-\delta)k_{I,t+1}\Big) \\ & + (1-\eta)\Big(pJ(a^-_{f,t+1}, k_{I,t+1}, z_{t+1}) + (1-p)J(a^+_{f,t+1}, k_{I,t+1}, z_{t+1})\Big)\Big], \end{aligned} \tag{14}$$

subject to (11) and (13), where $a_{f,t+1}$ is given by (6), and where $M_{t,t+1}$ is the discount factor of households that the firm uses to discount future dividends.

Firms' optimal choices for liquid capital, illiquid capital, labor for each production process, borrowing and dividends are given by $k_{L,t+1}(a_{f,t}, k_{I,t}, z_t)$, $k_{I,t+1}(a_{f,t}, k_{I,t}, z_t)$, $l_{L,t}(a_{f,t}, k_{I,t}, z_t)$, $l_{I,t}(a_{f,t}, k_{I,t}, z_t)$, $b_{t+1}(a_{f,t}, k_{I,t}, z_t)$, and $d_t(a_{f,t}, k_{I,t}, z_t)$.

2.2. Households

We now turn to the intertemporal optimization problem faced by a representative household. It maximizes its expected lifetime utility

$$\sum_{t=0}^{\infty} \beta^t u(c_t), \tag{15}$$

[4] It is also important to note that b_{t+1} is debt net of asset holdings given how it is defined. Asset holdings and their returns could in principle be pledgeable, and if that is the case then firms could hold a positive balance of assets in their balance sheet and simultaneously be borrowing. If debt is not risky, however, as is the case in this model, firms have no motive to do so. See Acharya et al. (2007) for a detailed discussion of this point.

where c_t is consumption and β is the discount factor. Households are the shareholders of the firms and own a perfectly diversified portfolio of all the firms in the economy, which pays a dividend each period equal to

$$D_t = \int_{\text{no exit}} d_t(a_{f,t}, k_{I,t}, z_t) d\Gamma_t(a_f, k_I) + \int_{\text{exit}} (a_{f,t} + \pi(1-\delta)k_{I,t}) d\Gamma_t(a_f, k_I) \tag{16}$$

where $\Gamma_t(a_f, k_I)$ is the joint distribution of asset holdings and illiquid capital holdings in the population of firms. In addition to equity shares, they hold an amount of riskless bonds issued by firms equal to a_{t+1}, which pay a return $1+r_{t+1}$.

The representative household is endowed with one unit of labor, which it supplies inelastically in return for a wage w_t. The household's budget constraint is

$$c_t + a_{t+1} = a_t(1+r_t) + D_t + w_t + T_t, \tag{17}$$

where T_t are lump-sum transfers provided by the government and financed by the corporate taxes paid by the firms.

2.3. Equilibrium

Given a sequence starting at time t of aggregate productivity and borrowing constraints which is denoted by $x_t = \{\theta_s, \mu_s\}_{s=t}^{s=\infty}$, let firms' choices for dividends, liquid investment, illiquid capital holdings, labor for liquid production, labor for illiquid production, and borrowing be given by $\{d_t(a_{f,t}, k_{I,t}, x_t)\}$, $\{k_{L,t+1}(a_{f,t}, k_{I,t}, x_t)\}$, $\{k_{I,t+1}(a_{f,t}, k_{I,t}, x_t)\}$, $\{l_{L,t}(a_{f,t}, k_{I,t}, x_t)\}$, $\{l_{I,t}(a_{f,t}, k_{I,t}, x_t)\}$, and $\{b_{t+1}(a_{f,t}, k_{I,t}, x_t)\}$, respectively, and choices by households for consumption and savings be given by $c_t(a_t, x_t)$ and $a_{t+1}(a_t, x_t)$, respectively. Let $\Gamma_t(a_f, k_I)$ denote the joint distribution of asset holdings and illiquid capital holdings in the population of firms. We are now ready to define an equilibrium.

Definition 1. An equilibrium is a sequence of interest rates $\{r_t\}$, a sequence of wages $\{w_t\}$, a sequence of transfers $\{T_t\}$, a sequence of consumption and savings policies $\{c_t(a_t, x_t)\}$ and $\{a_{t+1}(a_t, x_t)\}$, a sequence of dividends, liquid investment, illiquid capital holdings, labor for liquid production, labor for illiquid production, and borrowing given by $\{d_t(a_{f,t}, k_{I,t}, x_t)\}$, $\{k_{L,t+1}(a_{f,t}, k_{I,t}, x_t)\}$, $\{k_{I,t+1}(a_{f,t}, k_{I,t}, x_t)\}$, $\{l_{L,t}(a_{f,t}, k_{I,t}, x_t)\}$, $\{l_{I,t}(a_{f,t}, k_{I,t}, x_t)\}$, and $\{b_{t+1}(a_{f,t}, k_{I,t}, x_t)\}$, respectively, and a sequence of distributions for firms' asset and illiquid capital holdings $\{\Gamma_t(a_f, k_I)\}$, such that, given the initial distribution Γ_0 and an initial wealth of households a_0:

(i) $c_t(a_t, x_t)$ and $a_{t+1}(a_t, x_t)$ are optimal given $\{r_t\}, \{w_t\}$ and $\{T_t\}$,
(ii) $d_t(a_{f,t}, k_{I,t}, x_t)$, $k_{L,t+1}(a_{f,t}, k_{I,t}, x_t)$, $k_{I,t+1}(a_{f,t}, k_{I,t}, x_t)$, $l_{L,t}(a_{f,t}, k_{I,t}, x_t)$, $l_{I,t}(a_{f,t}, k_{I,t}, x_t)$, and $b_{t+1}(a_{f,t}, k_{I,t}, x_t)$ are optimal given $\{r_t\}$ and $\{w_t\}$,
(iii) Γ_t is consistent with the investment and borrowing decisions of firms and with aggregate taxes collected T_t,
(iv) the bond market clears:

$$\int b_{t+1}(a_{f,t}, k_{I,t}, x_t)\, d\Gamma_t(a_f, k_I) = a_{t+1}(a_t, x_t),$$

which requires that net aggregate borrowing of the firm sector (the left-hand side of the equation) is equal to aggregate saving of the household sector (the right-hand side), and finally
(v) the labor market clears:

$$\int l_{L,t}(a_{f,t}, k_{I,t}, x_t)\, d\Gamma_t(a_f, k_I) + \int l_{I,t}(a_{f,t}, k_{I,t}, x_t)\, d\Gamma_t(a_f, k_I) = 1. \tag{18}$$

2.4. Characterization of some properties of the equilibrium

To illustrate some of the properties of the model, it will be convenient to look at simplified versions in which some important features of the equilibrium can be characterized analytically. The analysis clarifies the two reasons why credit constraints create a bias towards liquid capital.

2.4.1. Current constraints and the perceived productivity of capital

This section shows that a firm with a binding credit constraint effectively perceives a higher rate of interest and discounts future output more, decreasing the perceived productivity of illiquid capital relative to liquid capital. Intuitively, the mostly long-run returns of illiquid capital do not relax the currently binding constraint and are penalized in present value terms, in contrast with the entirely short-run returns of liquid capital.

To provide clearer analytical results, we assume, without loss of generality, that there are no adjustment costs of capital, idiosyncratic shocks, labor input, or taxes, and that $\pi = 0$, so that capital has no liquidation value in the event of firm exit. In this simplified version, the constraint on the amount of borrowing b_{t+1} a firm can obtain becomes

$$b_{t+1} \le \mu \frac{f_L(k_{L,t+1}) + f_I(k_{I,t+1})}{1 + r_{t+1}}, \tag{19}$$

where the pledgeability parameter μ is constant for simplicity.

Denoting with λ_t and γ_t respectively the shadow values of the equity constraint (11) and the debt constraint (19), and assuming that these constraints are only binding in period t, so that the firm is unconstrained in all periods after t, the first order condition for the amount of liquid investment in period t is given by

$$1=\frac{f_L'(k_{L,t+1})}{(1+r_{t+1})\frac{(1+\gamma_t)}{(1+\mu\gamma_t)}}, \tag{20}$$

and the first order condition for illiquid investment is given by:

$$1=\frac{f_I'(k_{I,t+1})}{(1+r_{t+1})\frac{(1+\gamma_t)}{(1+\mu\gamma_t)}}+\sum_{j=2}^{\infty}\frac{(1-\eta)^{j-1}(1-\delta)^{j-1}f_I'(k_{I,t+j})}{(1+\gamma_t)\prod_{i=1}^{j}\prod(1+r_{t+i})}. \tag{21}$$

First order conditions (20) and (21) state that firms will invest until the cost of one additional unit of each type of capital, 1, is equal to the present value of its future stream of cash flows, discounted taking into account the shadow value of the current credit constraint. Firms effectively perceive a higher rate of interest to all maturities, through the effect of the shadow value γ_t of the binding borrowing constraint. But the discount rate adjustment is larger for maturities $t+2$ and beyond; the discount rate for marginal output of period $t+1$ is multiplied by the factor $(1+\gamma_t)/(1+\mu\gamma_t)$, while the discount rate for marginal output of period $t+2$ and beyond is multiplied by the factor $(1+\gamma_t)$, which is larger than $(1+\gamma_t)/(1+\mu\gamma_t)$ as long as $\mu>0$. The stronger discounting of longer term cash flows affects illiquid capital k_I only, because liquid capital k_L provides all of its returns in period $t+1$. This decreases the perceived productivity of illiquid capital relative to liquid capital.

The intuition behind this result is that increasing illiquid investment today only increases pledgeable output in period $t+1$, but does not produce any pledgeable output in periods $t+2$ and beyond, and those late cash-flows do not contribute to relaxing the borrowing constraint today. The penalty applied to these longer term cash-flows is equivalent to a steepening of the effective yield curve faced by the firm and as a result a stronger discounting of cash-flows received after period $t+1$, something which only affects the present value of illiquid investments.

2.4.2. *Anticipated constraints and the perceived productivity of capital*

We now show that a firm with future anticipated binding credit constraints also effectively perceives a relatively lower productivity of illiquid capital. Intuitively, future binding credit constraints increase the likelihood of having to terminate illiquid capital at a cost in the future, reducing its expected productivity. This does not affect liquid capital, which depreciates fully in one period.

To make this formal point, we also consider a simplified version of the benchmark model and abstract from adjustment costs of investment, labor input and taxes. Consider now that, for analytical tractability, the idiosyncratic operating cost shock parameter ε is a continuous variable with cumulative distribution function $G(\varepsilon)$ and support $[0,\varepsilon_{\max}]$. The first order conditions in an unconstrained setup for liquid and illiquid investment are

$$1=\frac{1}{1+r_{t+1}}E_t\left[f'(k_{L,t+1})-s_t\right], \tag{22}$$

for liquid capital, and

$$1=\frac{1}{1+r_{t+1}}E_t\left[f'(k_{L,t+1})-s_t+(\eta\pi+(1-\eta))(1-\delta)\right] \tag{23}$$

for illiquid capital. Expectations are taken over the realization of operating cost shock s_t. Expression (23) shows that the valuation of illiquid capital in period $t+1$ is equal to 1, unless the firm is forced to exit (which happens with probability η), in which case the valuation is $\pi<1$.

Turning to a context with financing constraints, consider that firms face borrowing constraint (19) and dividend constraint (11).[5] Firms might have to liquidate part of their illiquid capital stock if the current investment level will result in a negative asset position that violates (12) if a large cost shock occurs. The amount of illiquid capital that has to be liquidated is captured by variable $\sigma_t(k_{I,t},a_{f,t})$.

Denote with λ_t and γ_t respectively the shadow values of the equity constraint (11) and the debt constraint (19), and assume that these constraints are binding in every period . The first order conditions for liquid and illiquid investment are respectively:

$$1+\lambda_t-\gamma_t\mu f'(k_{L,t+1})=\frac{1}{1+r_{t+1}}E_t\left[\left(f'(k_{L,t+1})-s_t\right)(1+\lambda_{t+1})\right], \tag{24}$$

$$1+\lambda_t-\gamma_t\mu f'(k_{I,t+1})=\frac{1}{1+r_{t+1}}E_t\left[\left(f'(k_{I,t+1})-s_t\right)(1+\lambda_{t+1})+(\eta\pi+(1-\eta)(\sigma'_{k_I,t+1}\pi+(1-\sigma'_{k_I,t+1})))(1-\delta)(1+\lambda_{t+1})\right] \tag{25}$$

[5] For simplicity, and without loss of generality, we ignore the possibility of pledging undepreciated long term capital and the impact of the cost shock on the borrowing constraint.

Expression (25) shows that in the presence of financing constraints, the expected value of one unit of capital when the firm does not suffer the exit shock is

$$E_t(\sigma'_{k_I,t+1}\pi+(1-\sigma'_{k_I,t+1}))<1, \tag{26}$$

whereas in an unconstrained scenario the valuation of the undepreciated capital is always 1 if the firm is in operation (expression (23)). In particular, in a fraction $E_t\left(\sigma'_{k_I,t+1}\right)$ of the states in which the firm can continue to operate, it will need to liquidate the additional unit of capital invested at a low valuation of $\pi<1$, to avoid the possibility of ending with a negative asset position the following period. As a result, firms with future anticipated binding credit constraints effectively perceive a relatively lower productivity of illiquid capital.

3. Calibration and steady state analysis

This section first discusses how the two types of capital in the model map to their real world counterparts, and then introduces the calibration of the model. It ends by describing the firm policies and the distribution of firms in the steady state equilibrium that arises from the calibration.

3.1. Mapping capital types to their real world counterparts

The illiquid technology $f_I(k_{I,t+1}, l_{I,t})$ in our model produces most of its returns in the long run and utilizes capital that is partially irreversible, features which are meant to capture the notion that it is an investment to which the firm is tied to for a long period of time and can only undo at a cost.[6] The types of investment that fall into this category are R&D, firm-specific structures, and other long-term intangible capital items such as firm-specific human capital, firm branding, or growth options. Structures such as commercial or industrial property that are easily redeployable (e.g., urban offices) have a high resale value and investing in such an asset is effectively perceived by the firm as a short-term liquid investment given that it is not tied to it for a long period of time, despite the fact that it is irreversible and long-term.

One implication of our model is that these types of illiquid capital produce low collateral and attract a low amount of debt finance and instead are financed mostly by retained earnings, which can be thought of as internal equity. This is in line with existing empirical evidence. Brown et al. (2009) document that U.S. firms finance most of their R&D expenditures out of retained earnings and equity issues, an observation in line with the conclusion in Hall (2002) that R&D-intensive firms feature much lower leverage on average than less R&D intensive firms. Gatchev et al. (2009) document that, in addition to R&D, also marketing expenses and product development are mostly financed out of retained earnings and equity. Fama and French (2005) document that small, high-growth firms are more likely to use equity to cover their financing shortfalls, which can be interpreted as financing the option value of future growth opportunities with equity.

Further evidence consistent with the notion that long-term assets have less collateral value than short-term assets are the findings by the empirical literature that started with Rajan and Zingales (1998) that industries that rely more heavily on external finance grow faster in countries with better developed financial systems. Braun and Larrain (2005) show that these industries do worse in recessions. These authors cite the gestation period of a project as one of the key factors behind the degree of reliance on external finance. The evidence that firms that operate long-term assets are more affected by a deterioration of credit market conditions is consistent with the notion that long-term assets find it more difficult to attract external finance.

On the other hand, the liquid technology $f_L(k_{L,t+1}, l_{L,t})$ in our theory is characterized by a short maturity of its returns. The types of investment that fall into this category are inventory investment, investment in machinery and equipment, and structures with high resale value.

One implication of our theory is that these types of capital are mostly financed with debt, which has been shown empirically to be the case. This is perhaps most clear in the case of leases, which can be interpreted as collateralized debt financing in which the debtor can very easily repossess the leased asset in case of default. The structure of lease contracts, designed to facilitate repossession and redeployment of the leased asset, suggests that they are most useful in the case of assets that are not highly firm specific and can easily find alternative uses. Eisfeldt and Rampini (2009) report that a big share of machinery, equipment, buildings and other structures are financed with leases. Inventory investment and other assets with short maturities under one year attract substantial debt finance in the form of trade credit and bank credit lines (Petersen and Rajan, 1997; Sufi, 2009). Finally, investment in commercial real estate is primarily financed with mortgage loans (Benmelech et al., 2005). Furthermore, these authors find, consistent with the results in this paper, that higher asset redeployability leads to larger loans with longer maturities.

[6] Irreversibility refers to the firm's limited ability to reconvert illiquid capital into consumption goods in the short run within the firm. But if illiquid capital was easily redeployable and could be used productively by other firms, irreversibility would not be a problem. For this reason, illiquid capital is also assumed to have a high degree of firm-specificity and as a result a low redeployability and resale value to other firms.

3.2. Calibration

The calibration of the economy is done at the quarterly frequency, and the chosen values for the parameters are shown in Table 1. Some parameter values are set directly based on existing microeconomic and macroeconomic evidence. The remaining parameters are chosen in such a way that key aggregate variables from the simulated steady state of the model are close to their empirical counterparts. The process for choosing this last group of parameters is iterative and builds on the intuition provided by the model mechanics for which parameters are key for each moment. A summary of all the empirical moments used to calibrate parameters can be found in Table 2.

The utility function for households is chosen to be iso-elastic of the form

$$u(c_t) = \frac{c_t^{1-\varphi} - 1}{1-\varphi}, \tag{27}$$

with a constant relative risk aversion coefficient, φ, of 2. The intertemporal preference rate β is set at 0.99 to match an annualized average interest rate of approximately 4 percent.

The calibration of parameters concerning the firm sector can be divided into three categories: those that affect their production technologies, those that control firms' financing constraints, and those that determine firm entry and exit.

The firm technology parameters are $\gamma_L, \alpha_L, \gamma_I, \alpha_I, \theta_L$ and θ_I. Drawing on the existing empirical evidence on estimates of the degree of returns to scale at the firm level, γ_L, α_L, γ_I and α_I are set so that $\gamma_L + \alpha_L = \gamma_I + \alpha_I = 0.9$, in line with Thomas (2002) and Restuccia and Rogerson (2008). The precise values given to the liquid and illiquid capital and labor shares, $\{\gamma_L, \alpha_L\}$ and $\{\gamma_I, \alpha_I\}$ respectively, is based on the estimates in Corrado et al. (2009) of the income shares of labor, tangible capital, and intangible

Table 1
Parameter values.

Parameters	Explanation	Value
φ	Coefficient of relative risk aversion	2
β	Households' discount rate	0.99
α_L	Capital share in liquid technology	0.36
α_I	Capital share in illiquid technology	0.36
γ_L	Labor share in liquid technology	0.54
γ_I	Labor share in illiquid technology	0.54
θ_{SS}	Aggregate productivity factor (steady state)	1
θ_L	Productivity factor of liquid technology	0.7
θ_I	Productivity factor of illiquid technology	0.5
p	Probability of a negative operating cost shock	0.25
ε	Size of operating cost shock per unit of total capital	3
δ	Depreciation of illiquid capital	0.025
ζ	Multiplicative parameter of convex adjustment cost function	4
χ	Exponential parameter of convex adjustment cost function	2
μ_{SS}	Pledgeability of earnings	0.8
τ	Corporate tax rate	0.35
η	Exogenous probability of firm exit	0.025
π	Recovery value of illiquid capital	0.40

Table 2
Empirical moments targeted in the calibration.

Empirical moment	Source	Data	Model
Income share of intangible capital	(1)	0.15	0.15
Income share of tangible capital	(1)	0.25	0.25
Long-term investment over total investment	(2)	0.11–0.47	0.15
Median assets of young firms over median assets of all firms	(3)	0.47	0.52
Probability of negative profits (annual)	(3)	0.25	0.33
Standard deviation of the ratio of profits to sales (annual)	(3)	0.35	0.27
Median quarterly total asset growth	(3)	1.23%	2.5%
Adjustment costs as share of aggregate investment	(4)	0.2–6.2%	0.2%
Standard deviation of investment over capital (annual)	(5)	0.05–0.31	0.175
Average net leverage ratio	(6)	0.079	0.068
Job destruction rate (annual)	(7)	10%	10%
Share of firms that pay out dividends or repurchase shares	(8)	44%	23%
Share of credit constrained firms	(8)	50%	48%

(1) Corrado, Hulten and Sichel (2009), (2) Own calculations using Bureau of Economic Analysis (BEA) data, (3) Own calculations using Capital IQ-Compustat for U.S. listed firms, (4) Gourio and Kashyap (2007), (5) Cooper and Haltiwanger (2006) and Song and Wu (2015), (6) Bates et al. (2009), (7) Bilbiie et al. (2012), (8) Farre-Mensa and Ljungqvist (2016).

capital in the U.S. over the period 1993–2005, which are 60%, 25% and 15%, respectively.[7] Their empirical definition of intangible capital is broadly consistent with the definition in this paper of illiquid capital. It includes research and development, business investment in computer software, and spending on strategic planning, redesigning existing products, investments to gain market share, and long-term investments in brand names. Given that these empirical estimates are at the aggregate level, the larger aggregate income share of tangible capital, which maps into liquid capital in our model, can be due to a larger productivity θ_L of sectors that utilize tangible capital, or due to a larger input share of capital α_L in those sectors. There are no such estimates available that could allow one to make this distinction, and the assumption is made that capital shares are the same for both technologies, so that, after applying the adjustment for decreasing returns to scale, $\gamma_L = \gamma_I = 0.54$ and $\alpha_L = \alpha_I = 0.36$. The difference between productivity parameters θ_L and θ_I is then set so that the aggregate income shares of tangible and intangible capital are those estimated by Corrado et al. (2009). The level of these productivity parameters is set to match the median growth rate of firm size, which is driven by firm profitability. We calculate the median total asset growth for Compustat firms to be around 5% annually, or approximately 1.23% quarterly. The results of this paper are robust to alternative choices in which $\alpha_L > \alpha_I$ and $\theta_L = \theta_I$. Our model delivers a median quarterly total asset growth which is higher than in the data mainly because dividend payments in the model are lower than in the data (only 23% of firms pay dividends, compared to 44% in the U.S., according to Farre-Mensa and Ljungqvist (2016)). The dividend payout is lower than in reality because the model misses some key factors, mostly to do with agency frictions and information asymmetry, that encourage dividend payments in the real world. A higher asset growth makes it harder for financial constraints to matter because it enables firms to overcome them faster. Our calibration delivers an amount of aggregate liquid investment as a share of total investment in line with the one observed in the data. Using data from the Bureau of Economic Analysis (BEA), illiquid investment is considered to include R&D, and certain types of non-residential structures, software development and industrial equipment. Liquid investment includes inventory investment, equipment investment, and residential fixed investment. Illiquid investment as a share of total investment ranges between 11% and 47% over the period 2000–2013, depending on the classification of non-residential structures, software development and industrial equipment. The simulated share of illiquid investment falls within this range, close to the lower bound.

The parameters driving the degree of idiosyncratic risk, which are the probability p of suffering an operating cost shock, and the size ε of the shock per unit of capital, are calibrated to roughly match the ratio between the median size of young firms and the median size of the whole population of firms, and the standard deviation of the ratio of profits to sales, respectively. Using the Capital IQ-Compustat database for U.S. listed firms during 2002–2011, the ratio between the median total assets of young stock-exchange listed firms (those with less than 1 year following their IPO) and the median asset holdings of the whole population of listed firms is calculated to be 0.51. This same data delivers a standard deviation of the ratio of profits to sales of 0.35, calculated at the annual frequency. Our definition of profits is equal to after-tax profits, as defined in Section 2.1. Our calibration also produces a probability of negative profits which is similar to the one observed in our data, which is 25% at the annual frequency.

The depreciation rate of illiquid capital is set at $\delta = 0.025$, which is a standard value for quarterly Real Business Cycle (RBC) models. The adjustment cost function for illiquid investment, $\psi(i_{I,t})$, is assumed to adopt the functional form

$$\psi(i_{I,t}) = \chi i_{I,t}^{\zeta},$$

with values $\zeta = 2$ and $\chi = 4$ set to generate aggregate adjustment costs that are roughly equal to 0.2% of aggregate investment, in the lower end of the estimates discussed in studies of adjustment costs of capital such as Gourio and Kashyap (2007), and also to be broadly in line with the firm-level standard deviation of investment rates (investment over capital) observed in the data. These estimates vary considerably, and range from 0.05 when using a Compustat sample of large firms (Song and Wu, 2015) to 0.31 when using the more disaggregated plant-level Longitudinal Research Database that includes smaller firms (Cooper and Haltiwanger, 2006). Our model delivers a standard deviation of investment over capital in the middle of this range, reflecting the fact that it considers firms and not individual plants, but also that it captures the complete distribution of firms, including small firms. The recovery rate of illiquid capital, π, is set to match the observed average recovery rates of corporate bonds in cases of default (Chen, 2010), estimated at around 40%, which is a proxy for the recovery value of the firm's assets. The corporate tax rate τ is set at the U.S. level of 35%.

The steady state value for the parameter regulating borrowing constraints (μ_{SS}) is set to match the average net leverage ratio for Compustat publicly listed firms, which is 7.9% according to Bates et al. (2009) using data from 1980 to 2006. They calculate net leverage as the ratio of total debt minus cash holdings to the book value of total assets. Net leverage in our model is calculated as the current value of debt b_{t+1} minus asset holdings over the total value assets, assuming assets are marked to market and valued according to the current firm value $J(a_{f,t}, k_{I,t}, z_{SS})$, where z_{SS} is the steady state defined by $\{r_{SS}, w_{SS}, \theta_{SS}, \mu_{SS}\}$. In addition, the model produces reasonable values of the share of credit constrained firms and of dividend paying firms. Farre-Mensa and Ljungqvist (2016) provide estimates of the fraction of financially constrained firms in the U.S. They find that roughly three quarters of privately held firms are financially constrained. Within the sample of publicly listed firms, they report different estimates of the share of financially constrained firms that range between 10% and 45%. Given

[7] These estimates are in line with values used by other studies, such as Hall and Mairesse (1995) and McGrattan and Prescott (2012) who impute an intangible capital input share of 19.0% and 7.6%, respectively. The estimates for the labor share are also in line with values used in previous studies such as King and Rebelo (1999) and Thomas (2002).

these estimates, we target a share of financially constrained firms to be around 50% in our sample. Our measure of financially constrained firms in the model includes those firms whose borrowing constraint is binding, and those whose equity issuance constraint is binding.

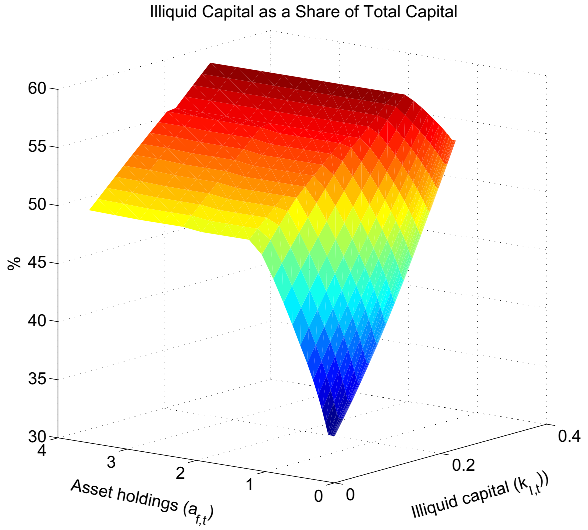

Fig. 1. The composition of the stock of capital at the firm level. The figure displays illiquid capital as a share of total capital, in the space defined by the firm's asset holdings $a_{f,t}$, and illiquid capital holdings $k_{I,t}$.

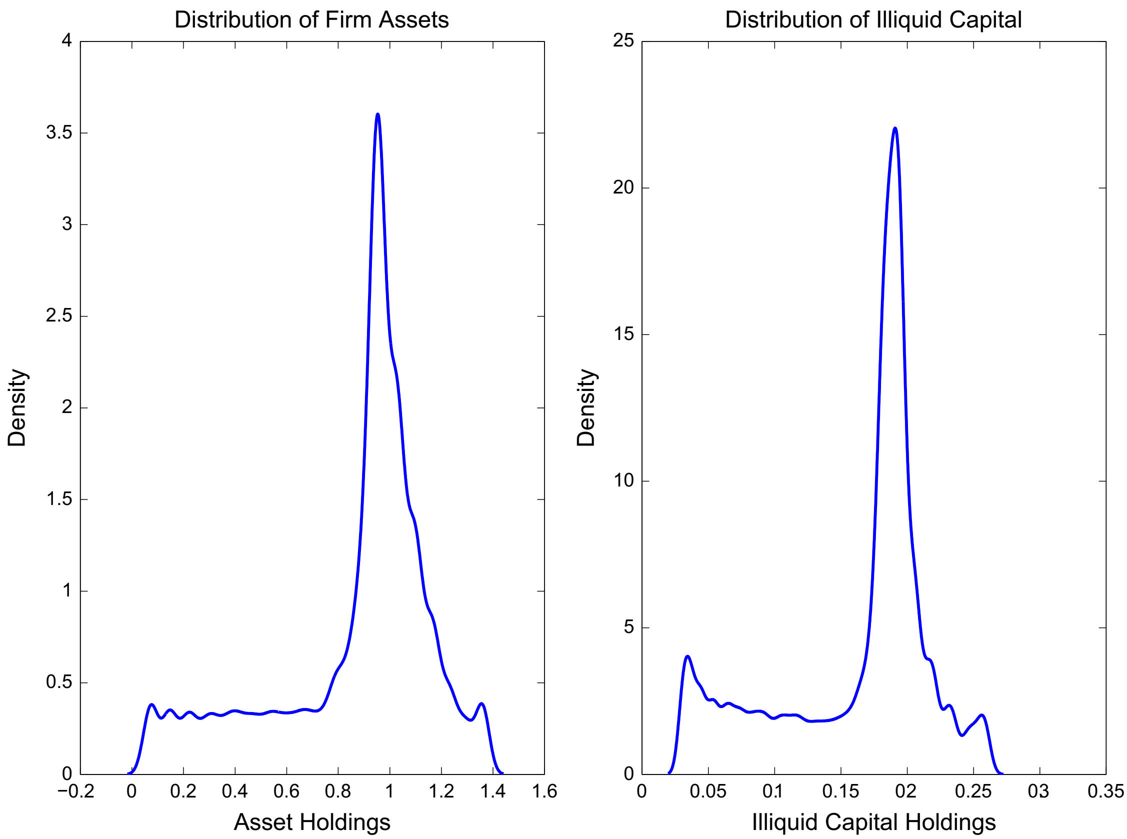

Fig. 2. Firm heterogeneity. This figure displays the distribution of asset holdings $a_{f,t}$ and illiquid capital holdings $k_{I,t}$ in the steady state equilibrium.

Finally, the exogenous firm exit shock $\eta = 0.025$ is set to match the U.S. empirical level of 10 percent job destruction per year, following Bilbiie et al. (2012). Exiting firms are immediately replaced by new firms with no holdings of assets or illiquid capital.

3.3. Firm policies and firm heterogeneity in the steady state

We now take a closer look at firm policies in the steady state equilibrium that arises from the calibration described above. The model is solved numerically using value function iteration and simulation techniques. A detailed explanation of the solution method for the steady state equilibrium can be found in the Appendix.

Fig. 1 displays illiquid capital as a share of total capital in the space defined by asset and illiquid capital holdings of the firm. Illiquid capital decreases significantly as a share of total capital as asset holdings of the firm decrease. Firms with very low asset holdings are credit constrained and have a bias towards liquid capital because illiquid capital produces less pledgeable output per unit of investment than liquid investment. But also the anticipation of future credit constraints creates a bias towards liquid investment. Idiosyncratic uncertainty interacts with financing constraints to favor liquid investments because illiquid capital runs the risk of having to be liquidated at a cost in the future if the firm runs into financial distress, meaning that illiquid capital has lower expected returns for firms with low liquid buffers, even if they are currently unconstrained.

Fig. 2 displays the distribution of asset and illiquid capital holdings, the two dimensions along which firms differ. Firms are created identical with no liquid assets or illiquid capital, and slowly build up the stock of both. The optimal asset holdings are determined by the trade-off between firms' desire to self-insure against the possibility of future negative operating cost shocks that weaken their financial position, and the desire to pay out dividends given that the after-tax return to cash holdings, $(1-\tau)(1+r_{t+1})$ is lower than the discount rate firms use, which is the equilibrium interest rate $(1+r_{t+1})$.[8] This optimal level is around 1 for most firms, although the precise value varies cross-sectionally as a function of the firm-level stock of illiquid capital. The speed at which the firm is able to accumulate assets is determined by the returns on cash holdings and by firm operating profitability. Similarly to asset holdings, firms have an optimal holding of illiquid capital, and for most firms this value is around 0.2, but some firms with particularly high asset holdings might be willing to hold a larger stock given that they face a lower risk of falling into financial distress and having to liquidate part of their capital at a cost.

4. Amplification and propagation of shocks

This section analyzes the dynamics of the economy following productivity and financial shocks.

4.1. Productivity shocks

In this section we study the transitional dynamics following an unexpected, temporary and persistent negative shock to aggregate productivity θ_t. The model is solved numerically using value function iteration and simulation techniques. A detailed explanation of the solution method for the transitional dynamics can be found in the Appendix.

We introduce an unanticipated shock in period s to aggregate productivity θ_t equivalent to -2% of its steady state value ($\theta_{SS} = 1$). Following the shock, θ_t evolves according to

$$\log \theta_t = \rho \log \theta_{t-1} \tag{28}$$

where $\rho = 0.9$. Firms and households learn about the productivity shock in advance of making their optimal choices in period $t=s$. As a result, firms are always able to repay any borrowing they undertook in period $t = s-1$. They have a perfect foresight about the evolution of θ_t from $t=s$ on.

To highlight the effect of firm financing frictions, we will compare the reaction of two different economies to this productivity shock. One economy will be the benchmark economy described in Sections 2 and 3 (the *financial frictions* economy), in which firms suffer from financing constraints. The other economy will be one in which firms do not suffer from financing constraints (the *unconstrained firms* economy). In the unconstrained economy, firms can pledge all of their future output to their lenders, and firms can access equity markets, which in the model corresponds to negative dividends. The calibration is otherwise kept unchanged for both versions of the model.

The responses of six key aggregate variables to the productivity shock are displayed in Fig. 3. The responses are calculated as percent deviations of each variable from their steady state value, except for the productivity shock, for which the actual value is plotted, and the share of illiquid investment over total investment, for which the absolute deviation in percentage points from its steady state value is plotted.

[8] The dynamic trade-off between the tax penalty on returns to cash holdings and the reduction in expected future financing costs conferred by holding cash has been addressed by Riddick and Whited (2009). The tax penalty of cash held inside the firm arises from a positive wedge between corporate and personal income taxes on interest income, which is in line with the current tax system in the U.S. In our model corporate income taxes are positive and there are no personal income taxes.

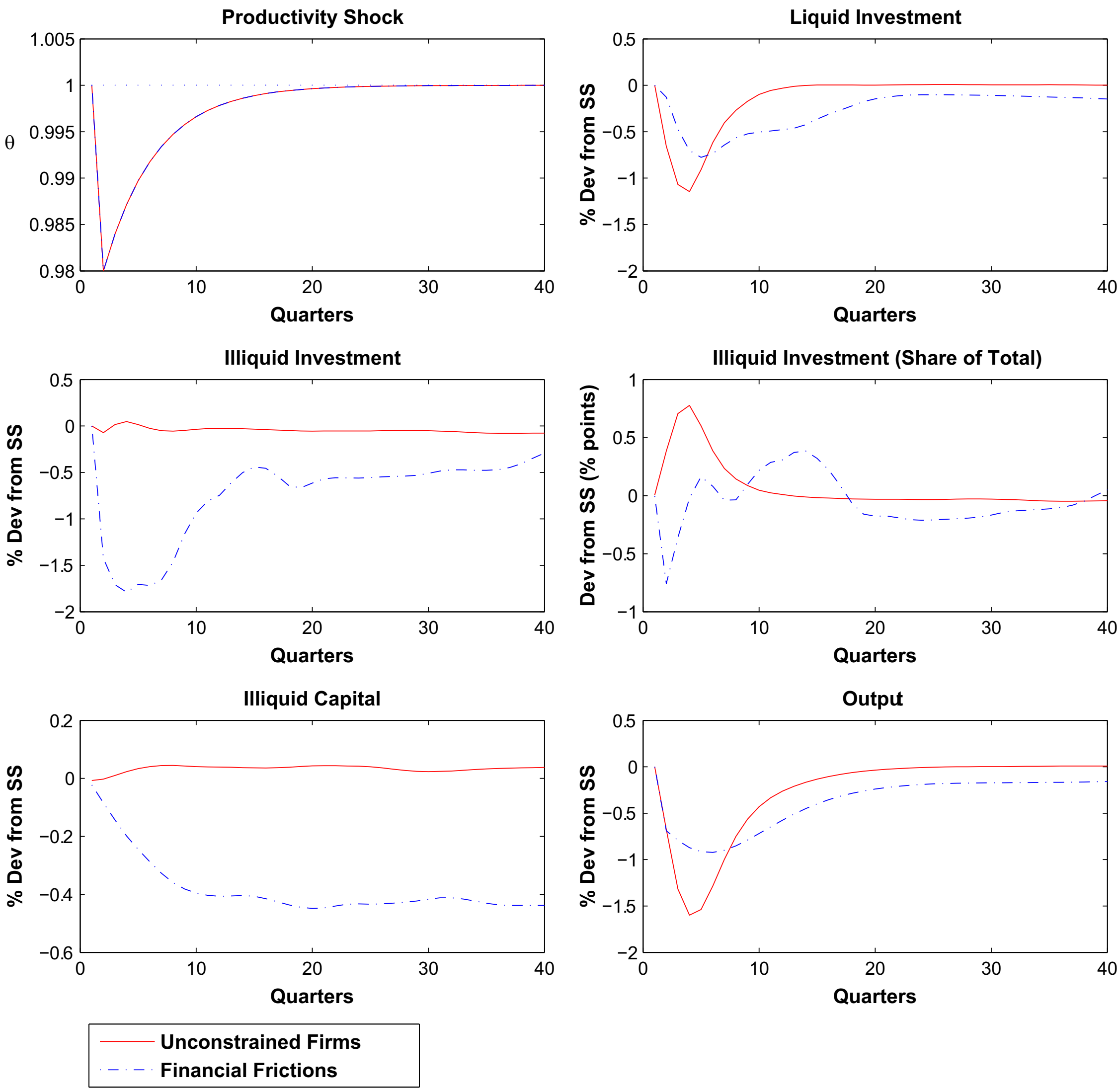

Fig. 3. Responses of key aggregate variables to a 2% negative shock to aggregate productivity θ_t. Responses are calculated as percent deviations of each variable from their steady state values, except for the productivity shock, for which the actual value is plotted, and the share of illiquid investment over total investment, for which the absolute deviation from its steady state value is plotted.

In the unconstrained economy, liquid investment drops following the shock, but illiquid investment is not very responsive. A temporary negative productivity shock decreases liquid investment returns significantly, because these returns all occur in the short run, but barely affects the mostly long-run illiquid investment returns, encouraging a shift towards illiquid investment. Illiquid investment as a share of total investment increases above its steady value for approximately 10 quarters, peaking at a share of 0.75 percentage points above its steady state value, and decreases slowly back to its steady state value. Output tracks the evolution of the productivity parameter θ closely, and there is little propagation of the shock.

Turning to the benchmark economy that features financial frictions for firms, the decrease in profits and net worth increases the share of firms with binding credit constraints. This can be seen in Fig. 4, which displays the responses to the shock of variables associated with firms' credit constraints. Firms' net worth recovers slowly so credit constraints are expected to remain tight for some time. Both the currently binding credit constraints and the anticipation of future constraints mean that many firms are unable or unwilling to sustain previous levels of illiquid investment, and instead increase the share of their investment allocated to liquid capital. Fig. 3 shows that illiquid investment falls by around 1.8% relative to its steady state value at its lowest point in quarter 4, while liquid investment falls less, by around 0.8% relative to its steady state value at its lowest point in quarter 5. As a result, illiquid investment as a share of total investment decreases by as much as 0.75 percentage points below its steady state value.

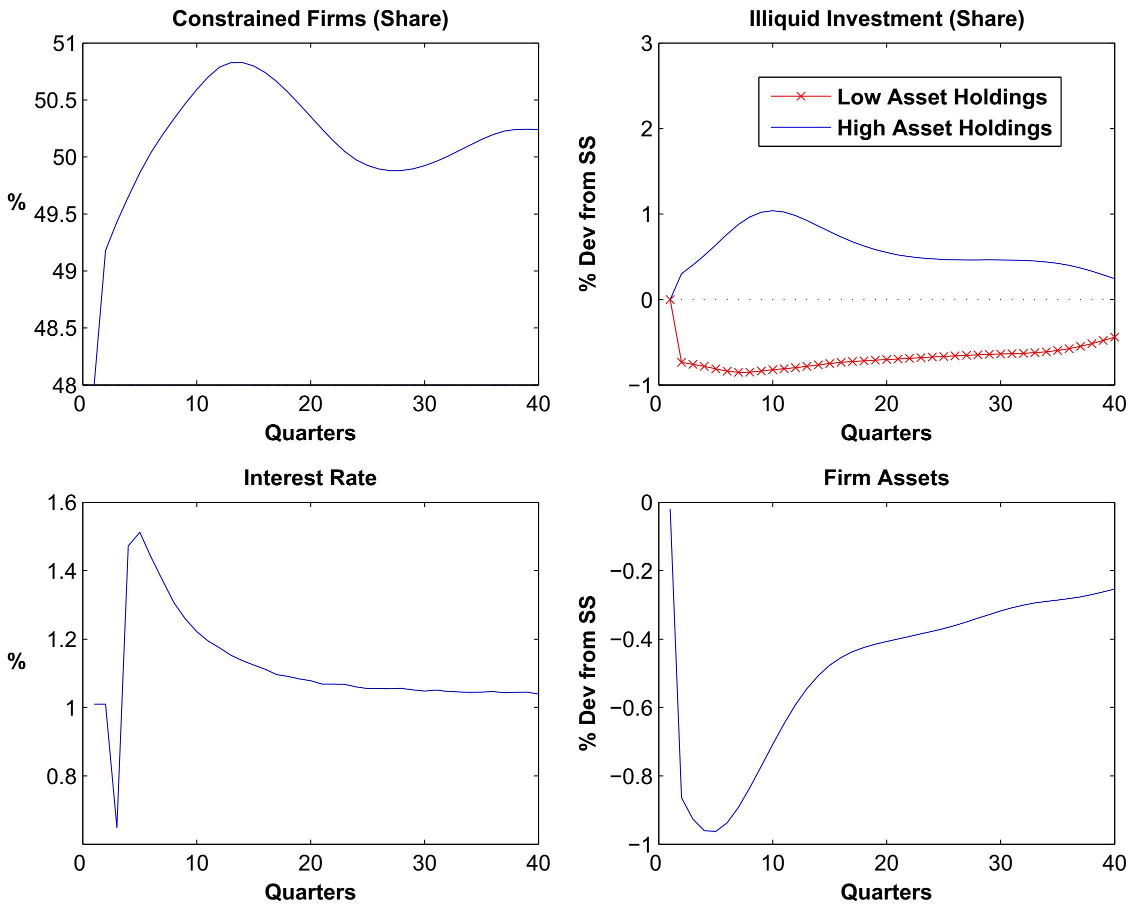

Fig. 4. Credit constraints following a 2% negative shock to aggregate productivity θ_t. The share of illiquid investment over total investment is calculated as the absolute deviation from its steady state value. Low (high) asset holdings firms are those whose asset holdings are in the lower (upper) tercile. Actual values are plotted for the interest rate. The response of firm assets is calculated as the percent deviation from its steady state value.

The large fall in illiquid investment translates into a large drop in the stock of illiquid capital. This stock takes many periods to recover due to the combination of costs of adjustment in investment and the loss of net worth in the firm sector. Firms' investment dynamics translate into a dampening of the effects of a negative productivity shock in the short run, and a strong propagation in the medium and long run. Output drops more and sooner in the unconstrained case; it bottoms at -1.6% relative to the steady state level in the fourth quarter following the shock, while the output drop in that quarter when firms face financing constraints is only -0.9% of its steady state value. In the medium and long run, the large initial drop in illiquid capital and its slow recovery means that the propagation of the effects of the shock is greater in the economy with financing constraints.[9]

The mechanism introduced in this paper affects the contemporaneous amplification and the intertemporal propagation of responses to shocks in opposite directions, so it is useful to calculate the integral of the deviations in output to gauge which effect dominates in determining total output loss in response to a negative shock. Total output loss over the 40 quarters following the shock is -15.2% of one quarter's output in the steady state in the financial frictions economy, and -10.6% in the unconstrained economy, a difference of 4.6%. This difference can be decomposed into a dampening over the first five quarters in the financially constrained economy by an accumulated amount equivalent to -2.3% of quarterly steady state output, and an additional propagation over the subsequent thirty-five quarters in the financially constrained economy relative to the unconstrained economy by an accumulated amount equivalent to 6.9% of quarterly steady state output. If future output is discounted using the households' quarterly discount rate $\beta = 0.99$, the accumulated difference over the 40 quarters falls to 3.3%. Clearly, the negative long-term effects of financial constraints dominate any positive short term effects, in terms of aggregate output.

[9] A lower equilibrium interest rate and wage could induce financially unconstrained firms to compensate for constrained firms' lower investment and hiring. The interest rate, after a small initial drop, actually rises above its steady state value for more than 20 quarters, because of the large decrease in household saving. Wages (not shown in the figure) do fall slightly, but not enough so that unconstrained firms make up for the lower investment and hiring of constrained firms.

4.1.1. Countercyclicality of financing constraints

Three mechanisms, displayed in Fig. 4, influence how tight borrowing constraints are along the transitional dynamics in the benchmark financial frictions economy. One is the decrease in firms' asset holdings following the shock. Another is the increase in interest rates, which decreases the present value of pledgeable output and tightens borrowing constraints. A third, novel, source of countercyclicality of borrowing constraints arises from the coexistence of liquid and illiquid investment opportunities. A temporary negative shock to productivity encourages a shift towards investing in illiquid capital because its returns are relatively more acyclical. Illiquid capital produces less pledgeable output per unit of investment, all else equal, so this shift towards illiquid investment results in tighter borrowing constraints. This novel mechanism to explain tighter borrowing constraints in recessions provides an alternative to the two main explanations offered in the literature, based on countercyclical agency costs on one hand,[10] and collateral constraints and lack of indexation of debt contracts on the other.[11]

Fig. 4 shows the combined effects of these mechanisms. The share of borrowing constrained agents increases from 48% to around 51%, and the increase is persistent. This increase occurs despite the fact that due to the negative productivity shock there is a decrease in demand for external funds to finance investment. If the behavior of high asset holdings firms and low asset holdings firms is compared, a classification that broadly captures financially constrained and unconstrained firms, respectively, we can observe that low asset holdings firms react by strongly shifting their investment towards the liquid project while high asset holdings firms only respond to the changes in the differential rates of return of short and long-term productivities and shift into illiquid projects.

4.2. Financial shocks

This section analyzes the transitional dynamics following an unexpected, temporary and persistent negative shock to the severity of financing frictions. In particular, an unexpected shock to μ_t, the parameter that determines the share of next period's output that can be pledged to lenders today, is considered. We compare the impact of shocks of two different sizes, equal respectively to 10% and 20% in absolute terms. In other words, μ_t decreases in $t=1$ unexpectedly from $\mu_{t=0}=0.9$ to $\mu_{t=1}=0.8$ in one case, and to $\mu_{t=1}=0.7$ in the other, and following the shock, for $t>1$, μ_t evolves according to

$$\log \mu_t = \rho \log \mu_{t-1} \tag{29}$$

where $\rho = 0.6$.[12] As with the technology shock, agents are assumed to learn about the shock in the period in which it occurs and have a perfect foresight about the evolution of μ_t from then on. The aggregate productivity factor θ_t is assumed to remain constant at its steady state value θ_{SS}. The resulting transitional dynamics are displayed in Fig. 5.

A tightening of financing constraints results in lower total investment in both cases. A 10% (20%) absolute decrease in the pledgeability of future output decreases total investment by around 10% (35%) at the trough, relative to total steady state investment. The impact of the financial shock is large, and increases disproportionately with the size of the shock. On top of the impact on the total quantity of investment, there are important compositional effects as well. The fall in illiquid investment in both cases is larger than the fall of liquid investment, and the difference increases more than proportionally in the size of the financial shock. A 10% financial shock is associated with a decrease in investment in illiquid capital as a share of total investment of around 4 percentage points (from 36% to 32%), while in the case of a 20% shock, this shift out of illiquid investment is of around 12 percentage points (from 36% to 24%). Two forces are at play. First, given that, on the margin, illiquid investment produces less pledgeable output than liquid investment, a tightening of credit constraints shifts investment towards the liquid project. Second, the tightening of credit constraints increases the likelihood that the firm will have to liquidate part of its illiquid capital following negative operating cost shocks, lowering the expected return of illiquid investment. The evolution of the distribution of firms' asset holdings enhances both effects. As firms become poorer, they need to finance a bigger share of their investment with external finance, which biases their investment towards liquid investment. Also, as they become poorer, they are more likely to be financially constrained in the future and to have to liquidate part of their illiquid capital.

Output drops by close to 2% four quarters after the impact of the 10% negative financial shock, and by close to 5% in the case of a 20% financial shock. The relative difference in the output reaction grows with time due the compositional effect and becomes up to five times stronger after ten quarters. The large decrease in illiquid investment in the case of a large shock means that the capital stock decreases strongly and recovers only slowly, due to the combined effect of convex costs of adjustment and credit constraints.

4.2.1. Anticipated future financial shocks and precautionary behavior

Credit constraints interact with the choice of liquidity of investment projects not just through currently binding credit constraints, but also through the possibility of future binding constraints. To isolate the precautionary behavior induced by future credit constraints, we conduct an exercise in which the firm learns about a future permanent shock to output

[10] As in Bernanke and Gertler (1989), Carlstrom and Fuerst (1997), or Christiano et al. (2010).

[11] As in Kiyotaki and Moore (1997) or Iacoviello (2005).

[12] The value for the quarterly persistence of the financial shock is taken from Hall (2011), who estimates the persistence of the increase in spreads during the financial crisis of 2008–2009.

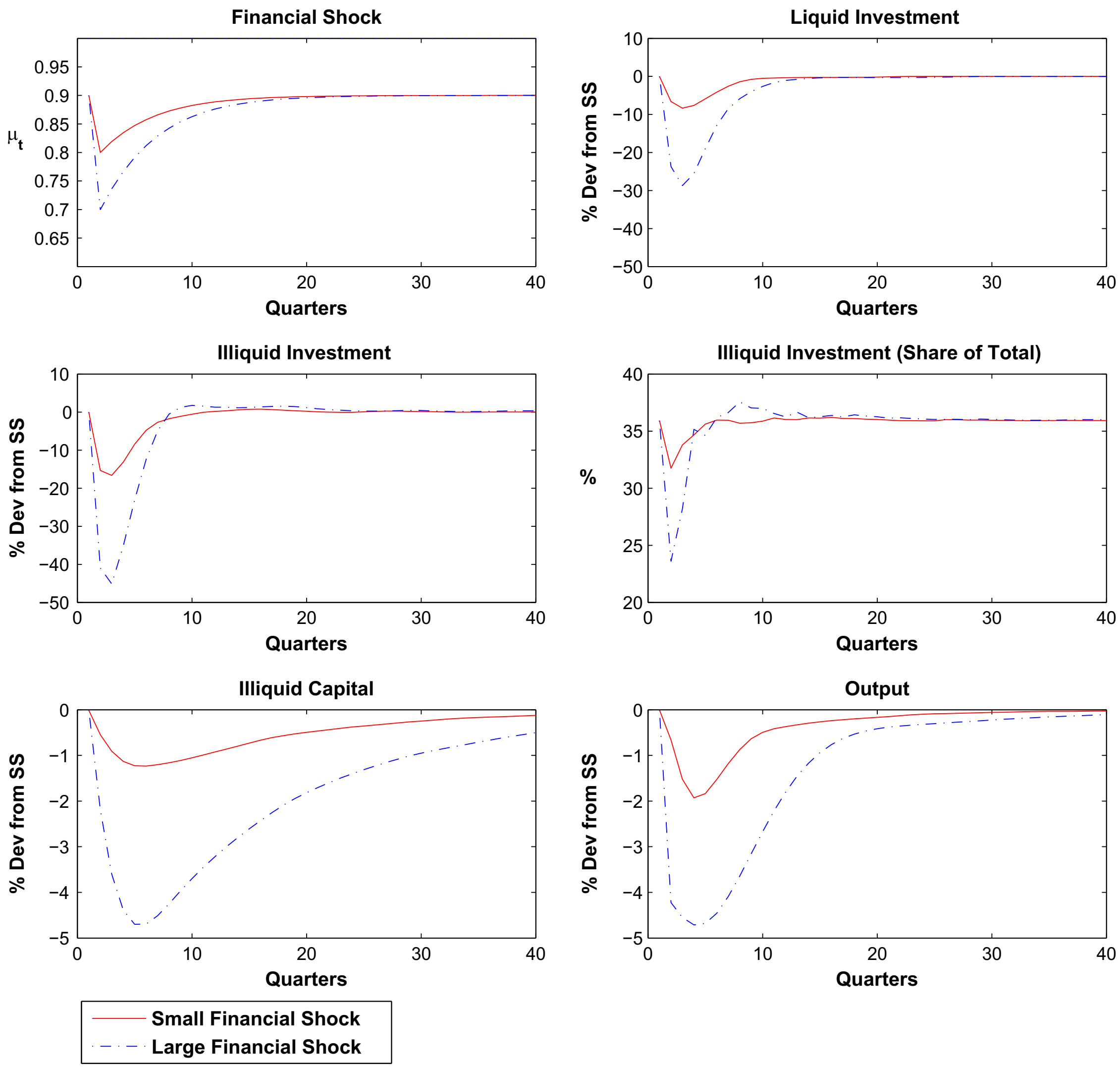

Fig. 5. Responses of key aggregate variables to a 10% and a 20% negative shock to financial constraints λ_t. Responses are calculated as percent deviations of each variable from their steady state values, except for the financial shock, for which the actual value is plotted, and the share of illiquid investment over total investment, for which the absolute deviation from its steady state value is plotted.

pledgeability factor μ_t that will occur 9 quarters ahead, and which will decrease μ from 0.9 to 0.6. The results of simulating such an exercise can be found in Fig. 6.

Firms react to the knowledge of a future tightening of credit constraints by increasing the liquidity of their portfolio of investment. In fact, liquid investment is above its steady state value for 4 quarters after the news of the shock, and starts decreasing sharply after the 6th quarter. Illiquid investment on the other hand decreases gradually over the 8 quarters between the news of the shock and the moment the shock hits, being close to 40% below its steady value immediately before the shock hits. As a result, output actually increases above its steady state value for 5 quarters, peaking at 0.75% above the steady state level of output. As the economy approaches the period in which credit constraints become tighter, output falls sharply due to both the accumulated decrease in illiquid capital and the decrease in liquid investment. This result points at the strong precautionary effect of future binding constraints.

5. Robustness and extensions

This section studies how sensitive the results in Section 4 are to variations in the degree and the nature of idiosyncratic risk, and to changes in features of the corporate income tax.

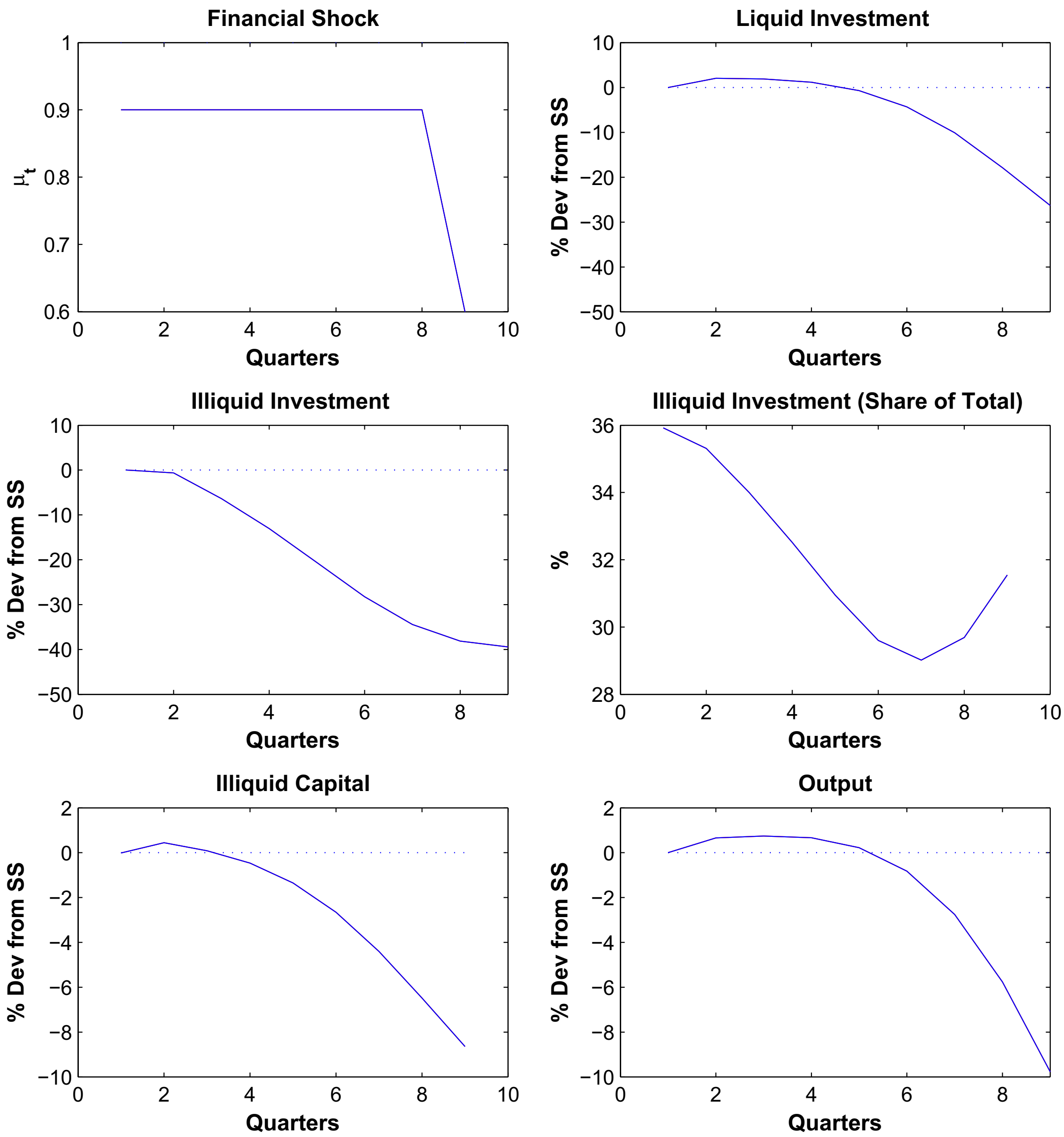

Fig. 6. Responses of key aggregate variables to a 30% negative shock to financial constraints λ_t that occurs in period 9. Responses are calculated as percent deviations of each variable from their steady state values, except for the financial shock, for which the actual value is plotted, and the share of illiquid investment over total investment, for which the absolute deviation from its steady state value is plotted.

5.1. *The role of idiosyncratic risk for firms*

This section studies how the degree and the nature of idiosyncratic risk affect the results in Section 4. Idiosyncratic uncertainty in the model takes the form of a shock to operating costs, and plays two roles. It is at the source of the second mechanism (the precautionary mechanism) through which financial frictions distort investment choices in favor of liquid projects, and it is necessary to be able to replicate the empirical cross-sectional distribution of firm size. If idiosyncratic uncertainty is removed, the result that firms with currently binding credit constraints allocate a smaller share of total investment to illiquid capital would still be present, but the second mechanism disappears, as the likelihood that the firm might suffer a negative shock that generates the need to liquidate illiquid capital would be absent. In terms of replicating the empirical distribution of firm size, a model with no idiosyncratic uncertainty would generate a flat distribution of firms with a spike in the right tail at the asset level at which firms start paying dividends.

The importance of idiosyncratic risk and the precautionary channel is evaluated by performing an exercise in which a mean preserving decrease in the volatility of the operating cost shock is introduced. The results are reported in Table 3. The

Table 3
Effects of variations in the volatility of the idiosyncratic cost shock.

Standard deviation of (profits/sales)	Initial dampening[a]	Long-run propagation[b]
0.35(benchmark)	2.3%	−6.9%
0.20	1.9%	−5.8%
0.10	1.5%	−4.9%

[a] Accumulated difference between the relative output fall in the financially constrained economy and the financially unconstrained economy, in the initial quarters after the shock during which the output fall in the financially constrained economy is less strong than the one in the unconstrained economy, relative to their respective steady states.

[b] Accumulated difference between the relative output fall in the financially constrained economy and the financially unconstrained economy in quarters after the shock during which the output fall in the financially constrained economy is stronger than the one in the unconstrained economy (up to quarter 40).

initial dampening and the medium run propagation of productivity shocks in the financial frictions economy relative to the financially unconstrained one both weaken, suggesting that idiosyncratic risk and the precautionary behavior that it induces in firms play an important role.

Idiosyncratic uncertainty for firms could be of a different nature, with potential implications for our results. To explore this possibility, idiosyncratic operating cost shocks are replaced with idiosyncratic productivity shocks, in the form of a stochastic and firm-specific productivity parameter $\theta_{i,t}$, where the subscript i refers to firm 'i'. Productivity shocks are a common device in the existing literature to introduce idiosyncratic uncertainty. To avoid adding an additional state variable to the firm problem, the idiosyncratic productivity shocks are assumed to be iid. Productivity risk of an iid nature makes short-run investment riskier, given that illiquid investment returns are subject to several independent productivity shocks throughout the lifetime of the project, while short-run returns are only subject to a single shock in the short run. As a result, firms' precautionary behavior induced by future credit constraints generates a smaller, though still strong, bias towards liquid investment. The bias arising from currently binding credit constraints remains the same. The results, using the same calibration targets as in our benchmark model, indicate that our dampening and propagation results are similar, although moderately weaker.

5.2. *Investment tax credits*

The U.S. corporate tax code has featured during several periods in the postwar era two main instruments for subsidizing capital expenditures; investment tax credits and allowed depreciation in excess of economic depreciation. This section studies the impact of the first feature, investment tax credits, given its more direct relationship with the distortions presented in this paper. Investment tax credits are modeled as an expensing allowance for the τ_d fraction of total investment, liquid or illiquid, done in that period. We first analyze this tax policy in the form of a permanent allowance, and secondly as a countercyclical allowance designed to alleviate the inefficiencies associated with the large decrease in illiquid investment in downturns.

The first policy measure, constant expensing allowances, is calibrated so that the credits as a share of total investment are around 2%, in line with recent U.S. evidence (McGrattan and Prescott, 2005). Such a policy decreases the distortion towards liquid investment of financially constrained firms by decreasing the current burden of illiquid investment, which attracts less external finance than liquid investment, but does not alter the qualitative or quantitative results concerning the response to shocks significantly.

The second policy measure, cyclical expensing allowances, are modeled as a variable expensing allowance for the $\tau_{d,t}$ fraction of total investment that depends on aggregate productivity θ_t in the following way:

$$\tau_{d,t} = \tau_{d,SS} + \varkappa(\theta_{SS} - \theta_t), \tag{30}$$

where $\varkappa > 0$ is calibrated so that the credits as a share of total investment during the first 5 quarters following the shock are roughly the same as at their peak in the U.S., which was in the late 1970's and early 1980's, when they were around 6% (McGrattan and Prescott, 2005). This policy is meant to capture the recent U.S. policy of temporary and partial expensing allowances on business equipment investment, one of the key countercyclical fiscal policies put in place in the recent crisis in the U.S. (Edge and Rudd, 2011). Introducing this policy has a noticeable impact on the dynamics of the composition of investment. This policy generates a reduction in short-run output and an increase in medium and long-run output, relative to the benchmark calibration absent cyclical expensing allowances. Initial dampening is decreased from 2.3% in our benchmark simulations to 1.8%. Long-run propagation is brought down from 6.9% in our benchmark simulations to 5.3%. This result points towards one of the key policy implications of the frictions modeled in this paper, which is that policies that are targeted towards eliminating distortions that reduce illiquid investment should be evaluated in the long term, as they might come at the cost of a drop in short-run output.

6. Conclusion

A model is introduced in which credit constrained firms can choose between investment projects that differ in the timing of their payoffs and the limits to pledge these future payoffs. Illiquid capital, which has a delayed timing profile of payoffs and can only be liquidated early at a large cost, cannot attract significant external funds when financing is restricted to safe debt and the firm suffers the risk of exit every period. The presence of idiosyncratic risk further increases the preference for liquid capital because illiquid capital might have to be terminated early at a cost if the financial condition of the firm deteriorates in the future.

We use this framework to explore how the consideration of firms' investment liquidity choice problem in the presence of financing frictions might affect the role of such frictions in amplifying or dampening shocks to the macroeconomy. A novel dampening mechanism of technology shocks is identified, which is shown to be quantitatively large. On the other hand, this framework is able to account for the empirically documented cyclical variation in the composition of investment, a feature which most existing models studying the macroeconomic implications of financial constraints cannot account for.

This paper highlights the importance for models designed to study the macroeconomic implications of credit constraints of considering the type of investment firms carry out, in addition to the amount. While this paper focuses on a particular set of dimensions of project heterogeneity, several other important dimensions remain to be analyzed in the context of a general equilibrium heterogeneous agent framework like the one presented in this paper, such as minimum investment size or volatility of returns. Models that incorporate these or other dimensions of heterogeneity could be fruitful avenues of research. Another potentially interesting extension of the current framework is the introduction of aggregate uncertainty. New insights could be derived in such a setting, such as the ex-ante distortions caused by the anticipation of aggregate shocks. Firms for example might react ex-ante to the possibility of negative aggregate or financial shocks by allocating a bigger share of their investment to liquid capital.

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Appendix A. Supplementary data

Supplementary data associated with this paper can be found in the online version at http://dx.doi.org/10.1016/j.jmoneco.2016.01.006.

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