Journal of Monetary Economics 70 (2015) 116–132

Contents lists available at ScienceDirect

Journal of Monetary Economics

journal homepage: www.elsevier.com/locate/jme

Liquidity, assets and business cycles ☆

Shouyong Shi *

Department of Economics, Pennsylvania State University, 502 Kern Building, University Park, PA 16802, USA

A R T I C L E I N F O

Article history:
Received 9 January 2013
Received in revised form
30 October 2014
Accepted 30 October 2014
Available online 7 November 2014

Keywords:
Liquidity
Asset prices
Business cycle

A B S T R A C T

The objective here is to evaluate the quantitative importance of financial frictions in business cycles. The analysis shows that a negative financial shock can cause aggregate investment, employment and consumption to fall with output. Despite this realistic comovement among macro quantities, a negative financial shock generates an equity price boom as the shock tightens firms' financing constraint. This counterfactual response of the equity price is robust to a wide range of variations in how financial frictions are modeled and whether financial shocks affect asset liquidity or firms' collateral constraints. Some possible resolutions to this puzzle are discussed.

1. Introduction

The financial crisis in 2008 has brought financial frictions to the forefront of policy debate and academic research. The severe shortage of liquid assets during the height of the crisis prompted the US government to inject a massive amount of liquidity into the asset market, in various forms of bailouts and quantitative easing. There is little doubt that the liquidity shortage in that crisis was caused by changes in economic fundamentals. Specifically, the realization that many asset-backed securities had much lower qualities and much higher default risks than previously thought triggered a flight of funds from those securities to safer and more liquid assets. Despite this critical role of the fundamentals, the crisis has raised a more general question about the role of asset market liquidity: Can exogenous shocks to such liquidity be an important cause of the business cycle?

An affirmative answer to this question is the basis of the following hypothesis that will be referred to as the *liquidity shock hypothesis*. A sudden drop in asset market liquidity, which may not necessarily be related to changes in economic fundamentals, causes the equity price to fall. The lower equity price reduces the funds for investment that a firm can raise by issuing equity and/or using equity as collateral on borrowing. Thus, investment falls, output falls and an economic recession starts. The objective of this paper is to formulate a model to evaluate this hypothesis quantitatively.

☆ An anonymous referee provided useful comments. This paper has been presented at the Cireq-Ensai macro conference (Rennes, France), U. Southampton, U. Waterloo, the Canadian Macro Study Group meeting (2012), the Fall Conference at the St. Louis Federal Reserve Bank (2012), the Econometric Society Summer meeting (2012), Zhejiang U. (China), Fudan U. (Shanghai), the Federal Reserve Bank of Chicago Workshop on Money, Banking, and Payments (2011), the Asian Econometric Society meeting (2011), the Canon Institute for Global Studies (Tokyo), the International Economic Association meeting (2011), and the Canadian Economic Association meeting (as the Bank of Canada Lecture, 2011). I am grateful to Nobu Kiyotaki for many conversations on the topic, to Andrea Ajello and Igor Livshits for comments, and to Andrea Ferrero for giving me some of the computing codes. Li Li provided excellent research assistance. I gratefully acknowledge financial support from the Canada Research Chair, the Bank of Canada Fellowship, the Social Sciences and Humanities Research Council of Canada, and Pennsylvania State University. The view expressed here is my own and does not reflect the view of the Bank of Canada.

* Tel.: +1 814 864 2745.
E-mail address: sus67@psu.edu

http://dx.doi.org/10.1016/j.jmoneco.2014.10.002
0304-3932/

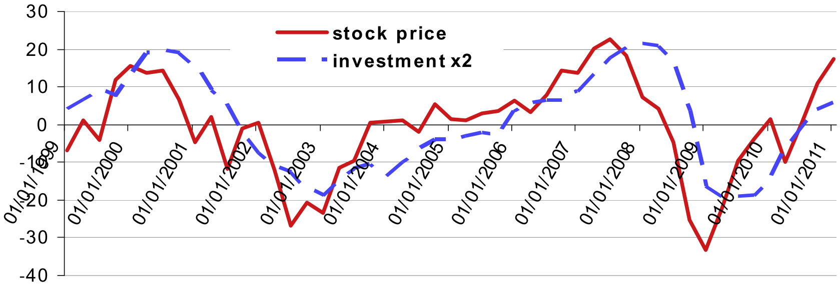


Fig. 1. Deviations of stock price and investment from the trend (%). Stock: deviation of the stock price from the trend (%). Investment: deviation of non-residential investment from the trend (%).

The liquidity shock hypothesis has become popular in macroeconomic analyses (e.g., Kiyotaki and Moore, 2012; Jermann and Quadrini, 2012). The intuitive appeal of the hypothesis comes partly from the link between investment and asset prices, which accords well with recent business cycles. Fig. 1 depicts the time series of a broad stock price index and non-residential investment in the US from 1999 to 2011. The series are percentage deviations of the quarterly data from the trend.[1] It is clear that investment and the stock price move closely together. More importantly, the stock price leads investment by one to two quarters in the business cycle. This lead-lag structure suggests that shocks might affect investment through asset prices.

Besides its intuitive appeal, the liquidity shock hypothesis has immediate policy implications. If asset liquidity is a cause of the business cycle, then a government can attenuate the cycle by supplying liquid assets counter-cyclically. In particular, by injecting liquidity to support asset prices in a recession, a government can prevent business investment from deteriorating precipitously, thereby stabilizing the economy. Such interventions are warranted when exogenous shocks to asset liquidity are the source of fluctuations.

Given its intuitive appeal and immediate policy implications, the liquidity shock hypothesis should be evaluated formally and clearly. For concreteness, this paper focuses on the version of the hypothesis modeled by Kiyotaki and Moore (2012, *KM*, henceforth). It will be shown later that the main result of this model holds in a much broader class of models that emphasize the financing constraint on investment. KM place two equity-market frictions at the center. One is the difficulty to issue new equity: a firm can issue new equity on at most a fraction $\theta \in (0,1)$ of investment. Another friction is the lack of resaleability of equity; that is, only a fraction $\phi \in (0,1)$ of existing equity can be resold in any given period. KM model a liquidity shock as an exogenous and unexpected change in ϕ.

I reformulate the KM model by assuming that each household consists of many members who perform different tasks in the market. While retaining the two equity market frictions in KM, this large-household construct simplifies the analysis significantly. It allows the use of a representative household which leads to straightforward aggregation of macro variables. The formulation leads to a recursive competitive equilibrium that is tractable in a stochastic and dynamic environment. Moreover, the formulation makes it relatively easy to incorporate both the equity liquidity constraint and a collateral constraint, thus allowing me to evaluate the liquidity shock hypothesis with a broad class of financial shocks.[2]

After calibrating to the US data, the model shows that a negative liquidity shock can cause aggregate investment, employment and consumption to fall with output. This positive comovement among macro quantities is a robust feature in the US data. The positive comovement between employment and consumption after a liquidity shock contrasts with the finding in KM. Despite the realistic comovement among macro quantities, a negative liquidity shock generates an asset price boom, which is opposite to what has been observed in recessions. This result casts doubt on the liquidity shock hypothesis.

The counterfactual response of the equity price to liquidity shocks is not unique to KM or to the particular form of the liquidity shock. Rather, it is a general feature of many models where equity is important for financing investment. To demonstrate this generality, debt finance is added to KM to capture the role of existing equity as collateral for a firm's borrowing. Specifically, the amount that a firm can borrow is proportional to the value of the firm's holdings of resaleable assets at the end of a period. Popularized by Kiyotaki and Moore (1997) and Jermann and Quadrini (2012), such a collateral

[1] The stock price index is the Wilshire 5000 price full cap index (Wilshire Associates Incorporated, also available at the Federal Reserve Data Center). This is an index of the market value of all stocks actively traded in the US, weighted by market capitalization. The designation "full cap" signifies a float adjusted market capitalization that includes shares of stocks not considered available to ordinary investors. The data is available on the daily basis, but the series used here is the price of the last trading day in each quarter. Investment is private nonresidential fixed investment, which is available at the US Department of Commerce: Bureau of Economic Analysis. The variables in Fig. 1 are quarterly data deflated with the GDP deflator, with the first quarter of year 2005 as the base period. They are filtered through the Hodrick–Prescott filter with a parameter 1600. I have multiplied the deviation of investment from its trend by 2.

[2] A similar household structure has been used in monetary theory by Shi (1997). In a related environment, Lucas (1990) uses a two-member household structure to facilitate aggregation.

constraint allows one to examine “financial shocks” that affect the ratio of a firm's borrowing capacity to the value of collateral. A negative liquidity shock reduces both the amount of resaleable equity and the borrowing capacity, but it still increases the equity price. Moreover, a negative financial shock alone also increases the equity price, even when liquidity is fixed. In fact, all shocks that reduce entrepreneurs' ability to finance investment tend to increase the equity price.

The equity price responds positively to a negative financial shock for a simple reason. Suppose that a negative shock of this type tightens the financing constraint on firm investment. Then, the demand for, and the price of, liquid assets will rise, as long as investment projects are still attractive. Because the portion of equity that remains resaleable is liquid, its price will rise as well. Section 5 will discuss some resolutions to the puzzle, all of which rely on direct or induced changes in effective productivity to accompany the liquidity shock.

Why should one be concerned about the counterfactual behavior of the equity price? After all, many macro models fail to generate realistic asset price movements, but some of these models remain useful for understanding macro fluctuations. For example, a standard real business cycle model has been widely used for capturing the comovement among major macro variables, although it predicts the real price of equity to be equal to unity. The unrealistic movements in the equity price are not a major concern in such a model, because they are not central to the story. This justification is not applicable when financial frictions are the main player, in which a fall in the equity price is supposed to be the primer of the transmission of a negative liquidity shock into aggregate quantities.

Other authors have independently discovered the puzzling response of the equity price to liquidity shocks. Nezafat and Slavik (2010) show that a negative shock to θ increases the equity price, and Ajello (2012) shows that a negative shock to ϕ increases the equity price. However, these authors do not focus on the puzzling response of the equity price. Instead, Nezafat and Slavik (2010) focus on the importance of shocks to θ in explaining the volatility of asset prices, and Ajello (2012) on the importance of shocks to the intermediation cost in explaining the volatility of investment and output. Another closely related paper is written by Del Negro et al. (2011), who quantitatively evaluate the non-standard policy intervention in the 2008. Both Ajello (2012) and Del Negro et al. (2011) incorporate a range of elements into KM, such as wage/price rigidity, adjustment costs in investment and habit persistence in consumption. These elements are intended to be realistic for addressing the issues in the two papers, but they cloud the picture of how liquidity shocks affect the equity price. I simplify the KM model rather than complicate it. The simplified model enables me to clearly illustrate the counterfactual response of the equity price to liquidity/financial shocks, identify the cause of this response, and demonstrate its robustness. Section 3.4 will explain why adding the aforementioned elements to the model does not overturn the counterfactual response of the equity price. The tractable formulation in this model should also be useful broadly for studying the role of the asset market in macro.

More generally, financial frictions have been the focus of business cycle research for quite some time (see Bernanke et al., 1999 for a partial survey). One approach emphasizes the role of financial intermediaries in economizing on the cost of lending to and monitoring entrepreneurs who have private information on project outcomes (see Townsend, 1979). Williamson (1987) seems the first to use this approach to study the business cycle, and Bernanke and Gertler (1989) construct popular models along this line. The main mechanism in this approach is that net worth of entrepreneurs and/or financial intermediaries is procyclical, which generates the financial multiplier. A related approach emphasizes a borrower's assets as collateral in borrowing when there is limited enforceability on debt repayment (see Kiyotaki and Moore, 1997; Jermann and Quadrini, 2012 and Liu et al., 2011). Section 4 will incorporate such a collateral constraint. Section 5 will compare with the literature further.

Proofs and the computation procedure are provided in the Supplementary Appendix.

2. A macro model with asset market frictions

This section describes the model and characterizes the equilibrium.

2.1. The model environment

Consider an infinite-horizon economy with discrete time. The economy is populated by a continuum of households, with measure one. Each household has a unit measure of members. At the beginning of each period, all members of a household are identical and share the household's assets. During the period, the members are separated from each other, and each member receives a shock that determines the role of the member in the period. A member will be an entrepreneur with probability $\pi \in (0,1)$ and a worker with probability $1-\pi$. These shocks are *iid* among the members and across time. An entrepreneur has an investment project and no labor endowment, while a worker has one unit of labor endowment and no investment project. The members' preferences are aggregated and represented by the following utility function of the household:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \{\pi u(c_t^e) + (1-\pi)[U(c_t^w) - h(\ell_t)]\}, \quad \beta \in (0,1).$$

The expectation is taken over aggregate shocks to (A, ϕ) which will be described below. The variable c_t^e is an entrepreneur's consumption, c_t^w a worker's consumption, and ℓ_t a worker's labor supply. The functions u, U and h are assumed to have standard properties. The household maximizes the above utility function by choosing all the actions which are carried out by the members. In the presence of ex post heterogeneity among the individuals, this large household structure facilitates aggregation.

The technologies in the economy are described below together with the timing of events in an arbitrary period t. The time subscript t is suppressed and the variables in period $t \pm j$ are given the subscript $\pm j$. A period is divided into four stages: households' decisions, production, investment, and consumption. In the stage of households' decisions, all members of a household are together to pool their assets. Aggregate shocks to (A, ϕ) are realized first (and so there is no need for precautionary savings). The household holds (physical) capital k, equity claims s, and liquid assets b. Capital resides in the household and will be rented to firms in the second stage to produce consumption goods. On every unit of capital there is a claim which is either sold to the outsiders or retained by the household. All claims on capital have the same liquidity, and so they have the same price. A household holds a diversified portfolio of equity claims on the capital stock in the economy. Liquid assets are government bonds. Because all members of the household are identical in this stage, the household evenly divides the assets among the members. The household also gives each member the instructions on the choices in the period contingent on whether the member will be an entrepreneur or a worker in the second stage. For an entrepreneur, the household instructs him to consume an amount c^e, invest i, and hold a portfolio of equity and liquid assets (s^e_{+1}, b^e_{+1}) at the end of the period. For a worker, the household instructs him to consume an amount c^w, supply labor ℓ, and hold a portfolio (s^w_{+1}, b^w_{+1}) at the end of the period. After receiving these instructions, the members go to the market and will remain separated from each other until the beginning of the next period.

At the beginning of the production stage, each member receives the shock whose realization determines whether the individual is an entrepreneur or a worker. Competitive firms rent capital from the households and hire labor from workers to produce consumption goods according to $y = AF(k^D, \ell^D)$, where the superscript D indicates the demand. The function F has diminishing marginal productivity of each factor and constant returns to scale. Total factor productivity A follows a Markov process. After production, a worker receives wage income, and an individual who holds equity claims receives the rental income of capital. Then, a fraction $(1-\sigma)$ of existing capital depreciates, where $\sigma \in (0,1)$, and every existing equity claim is rescaled by a factor σ.

The third stage in the period is the investment stage where entrepreneurs seek finance and undertake investment projects. To simplify, it is assumed that all investment projects are identical and each project can transform any amount $i \geq 0$ units of consumption goods into i units of new capital that will be added to next period's capital stock. In this stage, the asset market and the goods market are open. Individuals trade assets to finance new investments and to achieve the portfolio of asset holdings instructed earlier by their households.

In the final stage of the period, a worker consumes c^w and an entrepreneur consumes c^e. Then, individuals return to their households, arriving at the beginning of the next period.

There are two frictions in the equity market, as emphasized by KM. The first is that an entrepreneur can issue equity in the market on at most a fraction $\theta \in (0,1)$ of investment. The rest of the equity on new investment is retained temporarily by the entrepreneur's household. The second friction is that an individual can sell at most a fraction $\phi \in (0,1)$ of existing equity in a period. One may be able to explicitly specify the impediments in the asset market to generate these bounds endogenously.[3] As a first pass, however, θ is assumed to be fixed and ϕ to be exogenous, as in KM. Equity resaleability ϕ follows a Markov process. Shocks to ϕ are interpreted as shocks to equity liquidity.

The asset market frictions amount to putting a lower bound on an entrepreneur's equity holdings at the end of a period. Because of the bound on new equity issues, an entrepreneur must retain $(1-\theta)i$ claims on the new capital formed by his investment. In addition, after capital depreciates, the entrepreneur has σs claims on existing capital, of which the entrepreneur must hold onto at least the amount $(1-\phi)\sigma s$. Thus, the entrepreneur's equity holdings at the end of the period, s^e_{+1}, must satisfy the following equity liquidity constraint:

$$s^e_{+1} \geq (1-\theta)i + (1-\phi)\sigma s. \tag{1}$$

This lower bound can constrain the entrepreneur's financing ability when it is optimal to sell all the claims to raise funds for the investment project rather than hold onto some of them.

For (1) to be binding, an entrepreneur must face a tight borrowing limit. This limit is set as zero for now and will be relaxed in Section 4. The borrowing constraint is enforced by temporary separation of the members from each other in a period. Similar to the role in Lucas (1990), this temporary separation ensures that a household cannot shift funds within a period from its workers to its entrepreneurs to circumvent entrepreneurs' liquidity constraint. It captures the realism that it is costly to channel funds from one set of individuals to another set of individuals who have a better use of the funds.

Government policies are kept simple because they are not the focus of this paper.[4] In each period, the government spends g, redeems all matured bonds, issues an amount B of new real bonds, and collects lump-sum taxes τ, where (g, B, τ)

[3] For example, if new investment differs in quality which is the entrepreneur's private information, then the entrepreneur may not be able to finance the investment entirely with equity. Also, if investment requires an enterpreneur's (non-contractible) labor input as well as the input of goods, then moral hazard on labor input may put an upper bound on θ (see Hart and Moore, 1994). The difficulty in re-selling equity, as captured by $\phi < 1$, may be caused by the lemons problem in the asset market that induces asset prices to fall sharply as the quantity sold increases. Instead of modeling this difficulty with a smoothly decreasing function, I use the two-step function in KM to simplify the analysis.

[4] See Shi and Tewfik (2014) for an analysis of government interventions in the asset market.

are quantities per household. (If $\tau<0$, they are transfers to the households.) The government budget constraint is

$$g=\tau+(p_b-1)B, \tag{2}$$

where p_b is the price of bonds. The quantities (g,B) are assumed to be positive constants. To balance the government budget, τ must vary to eliminate any variation in the government revenue caused by the variation in the bond price.

2.2. A household's decisions

In a period, a household chooses $(i,c^e,s^e_{+1},b^e_{+1})$ for each entrepreneur and $(\ell,c^w,s^w_{+1},b^w_{+1})$ for each worker. In addition to the liquidity constraint, the household faces a resource constraint on each member. On an entrepreneur, the resource constraint is

$$rs+(b-p_b b^e_{+1})+q(i+\sigma s-s^e_{+1})\geq i+c^e+\tau, \tag{3}$$

where r is the rental rate of capital and q the price of an equity claim, measured in consumption goods. This constraint is explained as follows. An entrepreneur has three items of expenditure: consumption c^e, investment i, and the tax liability τ. The entrepreneur has three sources of funds to finance these expenditures. The first is the rental income of capital, rs. The second is the net receipt from trading liquid assets, $(b-p_b b^e_{+1})$, which is the amount obtained from redeeming matured bonds minus the amount spent on new bonds. The third is the net receipts from trading equity. After capital depreciates in the period, the entrepreneur holds σs claims on existing equity. The entrepreneur's investment creates i units of new capital. There is one claim on each unit of new capital, which is either sold to other households or retained by the entrepreneur for the household. Thus, the entrepreneur's total holdings of equity claims are $(i+\sigma s)$. Because the entrepreneur has to hold onto s^e_{+1} claims at the end of the period, the rest is sold to the market. Thus, the entrepreneur's net receipt from trading equity claims is $q(i+\sigma s-s^e_{+1})$.[5]

The focus is on the economy where the liquidity constraint (1) binds.[6] In this case, since an entrepreneur is constrained in the ability to finance investment, the entrepreneur will optimally push equity holdings at the end of the period to the minimum allowed by the liquidity constraint, and liquid asset holdings to zero. That is, s^e_{+1} satisfies (1) with equality, and $b^e_{+1}=0$. Substituting these optimal choices of (s^e_{+1},b^e_{+1}) into the entrepreneur's resource constraint, (3) yields the following consolidated *financing constraint* on the entrepreneur:

$$(r+\phi\sigma q)s+b-\tau\geq c^e+(1-\theta q)i. \tag{4}$$

The resaleability of equity increases an entrepreneur's ability to finance investment. Moreover, an entrepreneur's "downpayment"on each unit of investment is $1-\theta q$, because the entrepreneur can raise an amount θq by issuing equity in the market. Note that an entrepreneur's resource constraint (3) holds with equality, provided that the entrepreneur's marginal utility of consumption is strictly positive. Thus, an entrepreneur's liquidity constraint (1) is binding if and only if the consolidated constraint (4) is binding.

A worker faces a resource constraint similar to (3), except that a worker has labor income and no investment project. Let w be the real wage rate. This constraint is

$$rs+w\ell+q(\sigma s-s^w_{+1})+(b-p_b b^w_{+1})-\tau\geq c^w. \tag{5}$$

A worker's equity holdings at the end of the period should also satisfy the constraint: $s^w_{+1}\geq(1-\phi)\sigma s$. However, this constraint is not binding because, in the equilibrium, workers are the buyers of the new and existing equity sold by entrepreneurs.

Denote average consumption per member in the household as c and the average holdings of the portfolio per member at the end of the period as (s_{+1},b_{+1}). Then,

$$x=\pi x^e+(1-\pi)x^w,\ \text{ for } x\in\{c,s,b,s_{+1},b_{+1}\}. \tag{6}$$

Multiply (3) by π and (5) by $1-\pi$. Adding up yields the household's resource constraint:

$$(r+\sigma q)s-qs_{+1}+(1-\pi)w\ell+(q-1)\pi i+(b-p_b b_{+1})-\tau\geq c. \tag{7}$$

A household's decisions can be formulated with dynamic programming. The aggregate state of the economy at the beginning of a period is (K,Z), where K is the capital stock per household and $Z=(A,\phi)$ is the realizations of the exogenous shocks to total factor productivity and equity resaleability. The amount of equity per household and the supply of liquid assets are omitted from the list of aggregate state variables because the former is equal to K and the latter is a constant $B\geq 0$. Let $q(K,Z)$ be the equity, $p_b(K,Z)$ the price of liquid assets, $r(K,Z)$ the rental rate of capital, and $w(K,Z)$ the wage rate. All prices are expressed in terms of the consumption good, and the equity price is the post-dividend price measured after the rental income of capital is distributed to shareholders.

[5] Note that the liquidity constraint (1) ensures that the receipt from trading equity is strictly positive, which prevents the entrepreneur from going short on equity.

[6] As shown later, the necessary and sufficient condition for these constraints to bind is $1<q<1/\theta$, which is satisfied in the steady state in the calibrated economy.

A household's state variables consist of equity claims, s, and liquid assets, b, in addition to the aggregate state. Denote the household's value function as $v(s, b; K, Z)$. The household's choices in a period are $(i, c^e, s^e_{+1}, b^e_{+1})$ for each entrepreneur, ℓ for each worker, and (c, s_{+1}, b_{+1}) for the average quantities per member. Note that this list contains the quantities per member instead of the corresponding choices for a worker, $(c^w, s^w_{+1}, b^w_{+1})$. Similarly, the household's resource constraint (7) is used in lieu of a worker's resource constraint (5). When the financing constraint (4) binds, the optimal choices of (s^e_{+1}, b^e_{+1}) are $s^e_{+1} = (1-\theta)i + (1-\phi)\sigma s$ and $b^e_{+1} = 0$, respectively. The other choices, $(i, c^e, \ell, c, s_{+1}, b_{+1})$, solve:

$$v(s, b; K, Z) = \max\{\pi u(c^e) + (1-\pi)[U(c^w) - h(\ell)] + \beta \mathbb{E} v(s_{+1}, b_{+1}; K_{+1}, Z_{+1})\} \tag{8}$$

subject to (4), (7), and the following constraints:

$$i \geq 0,\ c^e \geq 0,\ c^w \geq 0,\ s^w_{+1} \geq 0,\ b^w_{+1} \geq 0, \tag{9}$$

where $(c^w, s^w_{+1}, b^w_{+1})$ are functions of (c, s_{+1}, b_{+1}) and $(c^e, s^e_{+1}, b^e_{+1})$ defined through (6). The expectation in the objective function is taken over next period's aggregate state (K_{+1}, Z_{+1}), and the arguments of price functions (r, w, q, p_b) in the constraints are suppressed.

Let $\lambda^e \pi U'(c^w)$ be the Lagrangian multiplier of the financing constraint, (4), where the rescaling by $\pi U'(c^w)$ simplifies various expressions below. Because $U'(c^w)$ is the Lagrangian multiplier of the household's resource constraint, (7), and π is the fraction of entrepreneurs in the household, λ^e is liquidity services provided by cash flows, measured in the household's consumption. As explained above, the liquidity constraint (1) binds if and only if $\lambda^e > 0$. Moreover, the optimal choices of (ℓ, c^e, i) yield:

$$\frac{h'(\ell)}{U'(c^w)} = w, \tag{10}$$

$$u'(c^e) = U'(c^w)(1+\lambda^e), \tag{11}$$

$$q - 1 \leq (1-\theta q)\lambda^e \quad \text{and} \quad i \geq 0, \tag{12}$$

where the two inequalities in (12) hold with complementary slackness.[7] Condition (10) is the standard condition for optimal labor supply. Condition (11) captures the fact that if an entrepreneur's financing constraint is binding, the value of a marginal unit of the resource to an entrepreneur exceeds the value to a worker by $\lambda^e U'(c^w)$. The conditions in (12) characterize the optimal choice of investment. Specifically, because each unit of investment requires a downpayment $1-\theta q$, the cost in terms of the household's utility is $(1-\theta q)\lambda^e U'(c^w)$. For the household, a unit of investment increases the resource by $(q-1)$, the benefit of which in terms of utility is $(q-1)U'(c^w)$. Investment is zero if the cost exceeds the benefit, and positive if the cost is equal to the benefit.

It is clear from (12) that the financing constraint is binding (i.e., $\lambda^e > 0$) if and only if $1 < q < 1/\theta$. Note that the direct cost of replacing a unit of capital is one. Thus, the equity price exceeds the replacement cost of capital if and only if the financing constraint binds. Intuitively, a binding constraint in financing investment creates an implicit cost that drives a wedge between the equity price and the replacement cost of capital.

Finally, the optimality conditions on asset holdings at the end of the period and the envelope conditions on asset holdings together give rise to the asset-pricing equations below:

$$q = \beta \mathbb{E}\left\{\frac{U'(c^w_{+1})}{U'(c^w)}[r_{+1} + \sigma q_{+1} + \pi \lambda^e_{+1}(r_{+1} + \phi_{+1}\sigma q_{+1})]\right\}, \tag{13}$$

$$p_b = \beta \mathbb{E}\left[\frac{U'(c^w_{+1})}{U'(c^w)}(1 + \pi \lambda^e_{+1})\right]. \tag{14}$$

If the financing constraint is expected not to be binding, then $\lambda^e_{+1} = 0$, in which case the asset-pricing equations reduce to the standard consumption-based asset-pricing formulas. If $\lambda^e_{+1} > 0$, the equations modify the standard formulas by incorporating liquidity services as additional implicit returns on the assets. The shadow price λ^e_{+1} enters the right-hand sides of both pricing equations because existing equity and liquid assets can both be sold to some extent to finance new investment, thereby relaxing the financing constraint. However, only a fraction ϕ_{+1} of existing equity can be sold next period while all liquid assets can be sold. Thus, ϕ_{+1} appears in the pricing equation for equity but not in that for liquid assets.

2.3. Definition of a recursive equilibrium

Let $\mathcal{K} \subset \mathbb{R}_+$ be a compact set containing all possible values of K, and $\mathcal{Z} \subset \mathbb{R}_+ \times [0,1]$ a compact set containing all possible values of Z. Let $\mathcal{C}_1$ be the set containing all continuous functions that map $\mathcal{K} \times \mathcal{Z}$ into $\mathbb{R}_+$, $\mathcal{C}_2$ the set containing all continuous functions that map $\mathcal{K} \times [0, B] \times \mathcal{K} \times \mathcal{Z}$ into $\mathbb{R}_+$, and $\mathcal{C}_3$ the set containing all continuous functions that map $\mathcal{K} \times [0, B] \times \mathcal{K} \times \mathcal{Z}$ into $\mathbb{R}$. A *recursive competitive equilibrium* consists of price functions $(q, p_b, r, w) \in \mathcal{C}_1$, policy functions

[7] The constraints $c^e \geq 0$, $c^w \geq 0$, $b^w_{+1} \geq 0$ and $s^w_{+1} \geq 0$ do not bind.

$(i, c^e, s^e_{+1}, b^e_{+1}, \ell, c, s_{+1}, b_{+1}) \in \mathcal{C}_2$, the value function $v \in \mathcal{C}_3$, the demand for factors, (k^D, ℓ^D), and the law of motion of the aggregate capital stock that meet the following four sets of requirements. First, given price functions and the aggregate state, a household's value and policy functions solve the optimization problem in (8). Second, given price functions and the aggregate state, factor demands satisfy $r = AF_1{}'(k^D, \ell^D)$ and $w = AF_2{}'(k^D, \ell^D)$, where the subscripts of F indicate partial derivatives. Third, given the law of motion of the aggregate state, prices clear the markets:

$$\text{goods:} \quad c(s,b;K,Z) + \pi i(s,b;K,Z) + g = AF(k^D, \ell^D), \tag{15}$$

$$\text{labor:} \quad \ell^D = (1-\pi)\ell(s,b;K,Z), \tag{16}$$

$$\text{capital:} \quad k^D = K = s, \tag{17}$$

$$\text{liquid assets:} \quad b_{+1}(s,b;K,Z) = b \equiv B, \tag{18}$$

$$\text{equity:} \quad s_{+1}(s,b;K,Z) = \sigma s + \pi i(s,b;K,Z); \tag{19}$$

Fourth, the law of motion of the aggregate capital stock is consistent with the aggregation of individual households' choices:

$$K_{+1} = \sigma K + \pi \ i(K,B;K,Z). \tag{20}$$

In the capital market clearing condition, the equality $K{=}s$ states the fact that there are claims on all capital. In the equity market clearing condition, new equity claims are equal to new investment, πi, because s is defined to include not only equity claims sold in the market but also claims retained by the household. Condition (20) is explicitly imposed here because it is needed for the households to compute the expectations in (8). However, because $K{=}s$ in equilibrium, the law of motion of the capital stock duplicates the equity market clearing condition – a reflection of the Walras' law.

Determining an equilibrium amounts to solving for asset price functions $q(K,Z)$ and $p_b(K,Z)$. Once these functions are determined, other equilibrium functions can be recovered from a household's first-order conditions, the Bellman equation in (8), the market clearing conditions and factor demand conditions. To solve for asset price functions, the right-hand sides of the asset pricing equations, (13) and (14), can be used to construct a mapping T that maps a pair of functions in $\mathcal{C}_1$ back into $\mathcal{C}_1$. The pair of functions (q, p_b) in an equilibrium is a fixed point of T. This procedure will be implemented numerically in Section 3.1. See the Supplementary Appendix for the equilibrium mapping T, the computation procedure, a discussion on the value of liquidity and the equity premium, and the analysis of the non-stochastic steady state. For comparative statics of a related model, see Shi (2012).

3. Equilibrium response to shocks

This section calibrates the model to examine the quantitative predictions.

3.1. Calibration and computation

The utility and production functions have the following standard forms:

$$U(c^w) = \frac{(c^w)^{1-\rho} - 1}{1-\rho}, \quad u(c^e) = u_0 U(c^e),$$

$$h(\ell) = h_0 \ell^\eta, \quad F(K,(1-\pi)\ell) = K^\alpha [(1-\pi)\ell]^{1-\alpha}.$$

The exogenous state of the economy (A, ϕ) obeys:

$$\log A_{t+1} = (1-\delta_A)\log A^* + \delta_A \log A_t + \varepsilon_{A,t+1}, \tag{21}$$

$$-\log\left(\frac{1}{\phi_{t+1}} - 1\right) = -\left(1-\delta_\phi\right)\log\left(\frac{1}{\phi^*} - 1\right) - \delta_\phi \log\left(\frac{1}{\phi_t} - 1\right) + \varepsilon_{\phi,t+1}. \tag{22}$$

The superscript $*$ indicates the non-stochastic steady state. These processes ensure $A \geq 0$ and $\phi \in [0,1]$. The quantitative analysis below will take ε_A and ε_ϕ as one-time shocks.

The length of a period is chosen to be one quarter and the non-stochastic steady state is calibrated to the US data. See the Supplementary Appendix for the steady state and the calibration. The values of the discount factor and the relative risk aversion are standard. So are the following targets and parameters. Aggregate hours of work in the steady state are 0.25. The share of labor income in output is $1-\alpha = 0.64$, the ratio of annual investment to capital in the steady state is $4(1-\sigma) = 0.076$, and the ratio of capital to annual output is 3.32. The steady state value of productivity is normalized to $A^* = 1$ and the persistence of productivity is $\delta_A = 0.95$. Government spending g is set to be 18% of steady state output. Note that the parameter u_0 is identified by the ratio of capital to output because u_0 affects entrepreneur's consumption which in turn affects investment and the capital stock. In contrast to many business cycle analyses, the elasticity of labor supply is

Table 1
Parameters and calibration targets.

Parameter	Value	Calibration target
β: discount factor	0.992	Exogenously chosen
ρ: relative risk aversion	2	Exogenously chosen
π: fraction of entrepreneurs	0.06	Annual fraction of investing firms $=0.24$
u_0: constant in entrep. utility	42.803	Capital stock/annual output $=3.32$
h_0: constant in labor disutility	24.404	Hours of work $=0.25$
η: curvature in labor disutility	2.0	Labor supply elasticity $1/(\eta-1)=1$
α: capital share	0.36	Labor income share (1-α)=0.64
σ: survival rate of capital	0.981	Annual investment/capital $=0.076$
A^*: steady-state TFP	1	Normalization
δ_A: persistence in TFP	0.95	Persistence in TFP $=0.95$
B: stock of liquid assets	2.021	Fraction of liquid assets in portfolio $=0.12$
ϕ^*: steady-state resaleability	0.273	Annual return on liquid assets $=0.02$
δ_ϕ: persistence in resaleability	0.9	Exogenously chosen
θ: fraction of new equity	0.273	Set to equal to ϕ^*
g: government spending	0.193	Government spending/GDP $=0.18$

deliberately chosen to be a relatively low value (one) in order to illustrate that aggregate responses in this model to liquidity shocks do not rely on highly elastic labor supply. All the results continue to hold when labor supply is more elastic.

Now turn to the remaining identification restrictions. First, the parameter π can be interpreted as the fraction of firms that adjust capital in a period. The annual estimate ranges from 0.20 (Doms and Dunne, 1998) to 0.40 (Cooper et al., 1999). The chosen value 0.24 lies in this range, which leads to π=0.06 quarterly. Second, θ is set to be equal to ϕ^* as a benchmark. Third, liquidity shocks must be persistent in order to generate persistent effects. Thus, the baseline calibration sets $\delta_\phi=0.9$. Fourth, the rate of return on liquid assets and the fraction of liquid assets in the total value of assets come from the evidence in Del Negro et al. (2011). These authors report that the annualized net rate of return on the US government liabilities is 1.72% for one-year maturities and 2.57% for ten-year maturities. A value in this interval, 0.02, is used.[8] Finally, Del Negro et al. (2011) use the US Flow of Funds between 1952 and 2008 to compute the share of liquid assets in asset holdings. Their measure of liquid assets consists of all liabilities of the Federal Government, that is, Treasury securities net of holdings by the monetary authority and the budget agency plus reserves, vault cash and currency net of remittances to the Federal Government. The sample average of the share of liquidity assets is close to 0.12, which is used as a target in the calibration.

Some of the identified values are worth mentioning. First, equity resaleability in the steady state is $\phi^*=0.273$, which indicates that the resale market for equity is far from being liquid.[9] Notice that ϕ^* is identified by the target that the annual yield on liquid assets is 0.02. If all assets were liquid, then the yield on liquid assets would be equal to the discount rate, $\beta^{-1/4}-1=0.0327$. The difference between the yield on liquid assets and the discount rate is accounted for by the liquidity service performed by liquid assets. Second, the price of equity in the steady state is $q^*=1.037$. Note that this value of q^* satisfies $1<q^*<1/\theta$, and so the financing constraint binds. Third, in the steady state, the rental rate of capital is $r^*=0.0271$ and the price of liquid assets is $p_b^*=0.9951$. So, the annualized equity premium in the steady state is $4(r^*/q^*+\sigma-1/p_b^*)=0.0087$. This premium is significant, considering that it is associated with the steady state where no risk is present.

Suppose that the error terms in the processes of A and ϕ are zero except possibly for t=1, as in the case of one-time shocks. The procedure in the Supplementary Appendix computes equilibrium price functions $(q,p_b)(K,Z)$, where $Z=(A,\phi)$. An individual household's policy functions are recovered as $x(s,b;K,Z)$, where x is any element in the list $(c,i,c^e,s^e_{+1},\ell,c^w,s_{+1},b_{+1})$. Since the equilibrium has s=K and b=B, where B is a constant, the notation $x(K,B;K,Z)$ is shortened as $x(K,Z)$. Most of the policy functions have predictable properties.

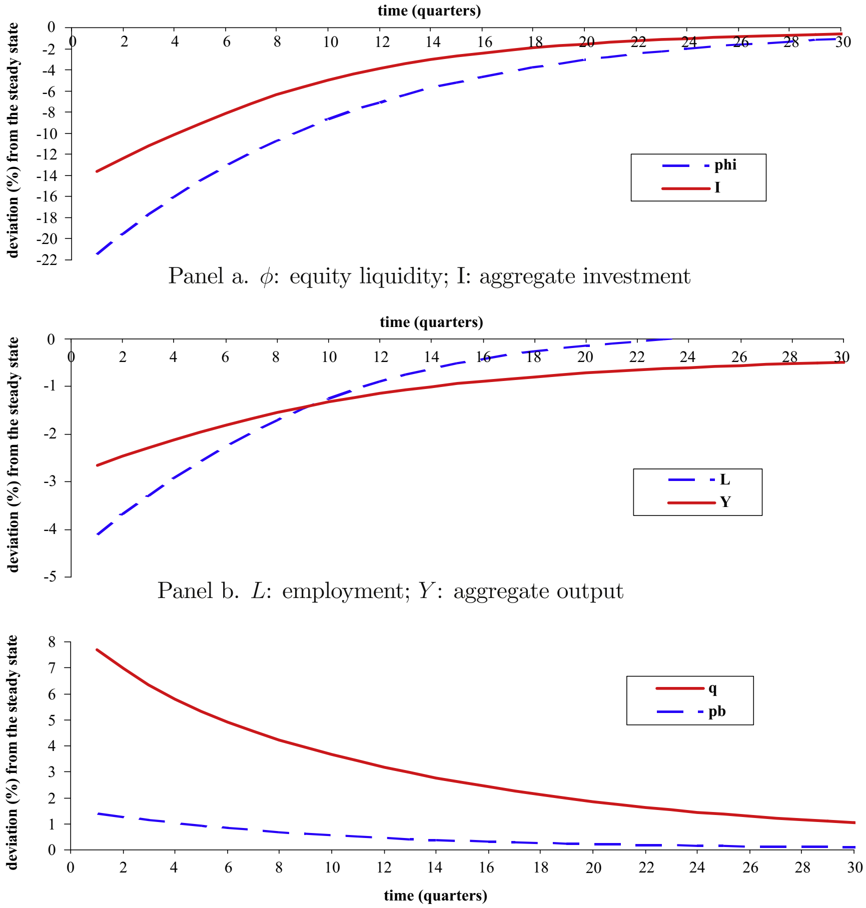
3.2. Equilibrium response to an asset liquidity shock

Suppose that the economy is in the non-stochastic steady state at time t=0. At the beginning of t=1, there is an unanticipated drop in liquidity to 0.214, a 22% drop from ϕ^*. After this shock, ϕ follows the process in (22), with $\varepsilon_{\phi,t}=0$ for all $t\geq 2$. To focus on this shock, the fraction of new equity issuance, θ, and total factor productivity, A, are fixed at their steady state levels. The dynamics are computed in the Supplementary Appendix.[10]

[8] The pricing equation for liquid assets in the steady state imposes the constraint $p_b^*\geq\beta$. Thus, given the value of β, the upper bound on the annual rate of return to liquid assets is $\beta^{-4}-1=0.0327$. Thus, the value chosen for the rate of return to liquid assets is in this feasible region.

[9] Nezafat and Slavik (2010) use the US Flow of Funds data for non-financial firms to estimate the stochastic process of θ. Interpreting θ as the ratio of funds raised in the market to fixed investment, they find that the mean of θ is 0.284. This is close to the value θ=0.273 used here.

[10] The non-linear asset price functions and policy functions are computed directly using Chebyshev projections and then used to simulate the dynamics after the shocks. Relative to linearizing the equilibrium system, this approach has the advantage of being able to deal with large shocks.



Panel a. ϕ: equity liquidity; I: aggregate investment

Panel b. L: employment; Y: aggregate output

Panel c. q: equity price; p_b: price of liquid bonds

Fig. 2. Equilibrium response to a negative liquidity shock.

Panel a in Fig. 2 graphs aggregate investment ($I=\pi i$) and equity liquidity, where the vertical axis is percentage deviations of the variables from their steady-state levels and the horizontal axis is the number of quarters after the shock. On impact of the negative liquidity shock in period 1, investment falls by 13.6%. Although the liquidity shock is large by construction, the size of the reduction in investment may still be surprising in the following sense. Because θ does not fall with the liquidity shock in this experiment, entrepreneurs can still issue new equity to finance new investment. The large fall in investment indicates that a majority of new investment is financed by selling existing equity and using other cash flows rather than issuing new equity. Panel a in Fig. 2 also shows that investment closely follows the dynamics of equity liquidity.

Panel b in Fig. 2 exhibits percentage deviations of aggregate employment ($L=(1-\pi)\ell$) and output (Y) from the steady state. Both variables fall by significant amounts when the negative liquidity shock hits in period 1. Employment falls by 4.2% and output by 2.7%. The reduction in output in period 1 comes entirely from the reduction in employment, because total factor productivity is fixed in this experiment and the capital stock in period 1 is predetermined. After period 1, however, the capital stock also falls below the steady state due to lower past investment, which keeps output low. The responses of these aggregate variables are persistent. Three years after the shock, employment and output are still below the steady state by more than 1%. Not all aggregate quantities respond to the shock in a realistic way. In particular, aggregate consumption (not depicted) increases in period 1 and approaches the steady state from above. However, this counterfactual response can be reversed with the introduction of adjustment costs in investment (see Section 3.4). Overall, the responses of aggregate quantities seem to suggest that shocks to asset liquidity can potentially be an important cause of aggregate fluctuations.

Before jumping on the bandwagon, it is important to check how asset prices respond to the shock. As panel c in Fig. 2 shows, a negative liquidity shock generates an asset price boom! On impact of the shock, the equity price increases by 7.7% and the price of liquid assets by 1.4%. Asset prices stay above the steady state for a long time. Three years after the shock, the equity price is still 3% above the steady state. The negative liquidity shock can generate a large and persistent response in the equity price, but the direction is opposite to the liquidity shock hypothesis and opposite to what is observed in the data. This miss is a serious problem, because the liquidity shock hypothesis necessitates a fall in the equity price to transmit a negative liquidity shock into aggregate quantities.

3.3. What is the cause of this problem?

One suspect is the fixed fraction of investment, θ, that can be financed by issuing new equity. I will investigate the likely scenario that θ falls with ϕ. Another suspicion is that the abstraction of the model from many realistic elements might have forced some variables to respond to the liquidity shock in the wrong magnitude or direction and, to make up for these incorrect responses, the equity price might respond in the wrong direction. The following is a partial list of omitted elements: wage rigidity, habit persistence in consumption, and adjustment costs in investment.

The effort to incorporate the above elements will be futile in overturning the positive response of the equity price to a negative liquidity shock. So will be the effort of allowing θ to fall together with the shock. To explain, it is useful to examine the condition of optimal investment, (12). When investment is positive, this condition becomes:

$$q-1=(1-\theta q)\lambda^{e}. \tag{23}$$

Because this equation is central to the argument, it is useful to repeat the meanings of the terms in it. q is the market price of equity, and λ^e is the shadow price of the financing constraint, (4). Both prices are measured in the household's consumption. For each unit of capital formed by investment, the price is q, the direct marginal cost is one, and so the benefit of investment is $(q-1)$. If there were no frictions in the equity market, investment could be positive and finite in the equilibrium if and only if $q=1$. Since there are frictions in issuing new equity, as modeled by $\theta<1$, the funds raised by issuing new equity are θq. The remainder of the funds for the investment, $1-\theta q$, must come from other sources. The cost of this downpayment on investment depends on the implicit cost of the financing constraint (4). Thus, $(1-\theta q)\lambda^e$ is the implicit marginal cost of a unit of investment. Condition (23) requires the marginal benefit of investment to be equal to the marginal cost.

Condition (23) provides a simple explanation for why the equity price increases after a negative liquidity shock. The condition contains only two variables, the equity price q and the shadow price of the financing constraint, λ^e. For any given λ^e, the marginal benefit of investment is strictly increasing in q, and the downpayment on investment is strictly decreasing in q. As long as a negative liquidity shock reduces an entrepreneur's ability to finance the downpayment of investment, the shock tightens the financing constraint (4). When the tightening increases the shadow price of the financing constraint in terms of the household's consumption, λ^e, the implicit marginal cost of investment rises for any given the equity price. To restore the balance between the marginal benefit and cost of investment, the equity price must increase.[11]

This explanation is general and can be phrased as a *rule of thumb*: Whenever a shock increases λ^e by tightening the financing constraint, all assets that help raise funds for investment experience price gains because they become more valuable to the entrepreneur. The resaleable portion of equity is one such asset, and liquid assets are another. At the risk of over-simplification, I phrase the result in terms of the demand for and the supply of equity. A reduction in equity liquidity reduces the supply of equity. The demand for equity is not affected by as much, because there is no change to the quality of investment projects. As a result, the equity price must increase to clear the equity market. With this generality, the argument can survive a wide range of variations of the model and the liquidity shock, as discussed below and in Section 4.

Consider first the plausible scenario that θ falls with ϕ. This concurrent fall in θ exacerbates the problem in the response of the equity price to ϕ. Because the reduction in θ further tightens an entrepreneur's financing constraint, it makes the resaleable portion of equity even more valuable than if θ is fixed. This effect is clear from (23). For any given the equity price and given ϕ, a fall in θ increases the downpayment needed for each unit of investment, which increases the implicit marginal cost of investment. To restore the balance between the marginal benefit and cost of investment, the equity price must rise even further after a negative liquidity shock.[12]

Next, consider the large household construct used in this model. With this construct, entrepreneurs and workers in a household pool their assets at the beginning of each period, and so heterogeneity in asset holdings among individuals created by trade during a period lasts only for one period. Because this pooling allows entrepreneurs in the next period to use the assets accumulated by other members in the current period, it reduces the persistence of the negative liquidity shock on an entrepreneur's financing constraint. When such pooling is not allowed, as in KM, the financing constraint will be tighter, which will require the equity price to increase by even more in response to a negative liquidity shock.

Another assumption in this model and in KM is that an entrepreneur has an immediate access to capital income in the period. That is, the income rs is available for financing current investment, as can be seen from (3). One may consider the alternative timing according to which the income rs is available only for financing consumption at the end of the period but not for financing investment in the current period. In this case, a fall in equity resaleability will tighten the financing constraint to a greater extent than it does in the current model and, hence, will increase the equity price by even more.

[11] Because λ^e is measured in the household's consumption, it is the shadow price of the financing constraint divided by $\pi U'(c^w)$, where $U'(c^w)$ is the household's marginal value of resources. Theoretically, λ^e can either rise or fall after a negative liquidity shock, even though a rise in λ^e is the intuitive outcome. Specifically, λ^e falls if and only if a negative liquidity shock tightens the household's resource constraint (7) by more than the financing constraint (4). Although theoretically possible, this outcome is highly implausible, because the main frictions lie in financing investment. However, because of this theoretical ambiguity, the analysis here is quantitative, and the main result is a rule of thumb rather than a theorem.

[12] This explanation suggests that a negative shock to θ by itself increases the equity price even if ϕ is fixed, a result consistent with the finding in Nezafat and Slavik (2010).

3.4. Robustness to adding the usual elements

The usual elements considered in this subsection are wage rigidity, habit persistence in consumption, and adjustment costs in investment.

Wage rigidity and habit persistence do not directly affect the marginal benefit and cost of investment, as it is clear from (23). Their indirect effects may tighten the financing constraint even further and exacerbate the problem in the response of the equity price to a liquidity shock. To see this, consider wage rigidity first. When there is a fall in equity liquidity, labor demand and output are likely to fall by more with rigid wages than with flexible wages. As a result, the rental income of capital will fall by more when wages are rigid. Because capital income is part of the funds for financing investment, the financing constraint (4) becomes tighter, and so the equity price rises by more with rigid wages than with flexible wages. Next consider habit persistence in consumption. When an entrepreneur cannot adjust consumption quickly because of habit persistence, the entrepreneur needs resource not only to finance investment but also to support persistently high consumption. Again, a negative liquidity shock will tighten the financing constraint (4) by more in this case than when there is no habit persistence, which requires the equity price to increase by more.

In contrast to wage rigidity and habit persistence, adjustment costs in investment directly affect the condition of optimal investment. To illustrate that a negative liquidity shock still increases the equity price in the presence of adjustment costs, I briefly sketch the analysis with adjustment costs below. This analysis also serves the purpose of improving the response of aggregate consumption to the liquidity shock. In the baseline model, a negative liquidity shock reduces investment by so much that aggregate consumption increases. With adjustment costs in investment, the negative liquidity shock can reduce aggregate consumption.

For concreteness, I adopt the conventional assumption that entrepreneurs purchase newly installed capital goods from capital-goods producers who are perfectly competitive. Producing and installing I units of new capital costs $[I+I^*\Psi(I/I^*)]$ units of consumption goods, where I^* is steady-state investment and Ψ satisfies $\Psi(1)=0$, $\Psi'(1)=0$, and $\Psi''>0$. Let p_I denote the price of newly installed capital. A capital-goods producer maximizes profit, $p_I I-I-I^*\Psi(I/I^*)$, and the optimal choice of I satisfies $1+\Psi'(I/I^*)=p_I$. Profit of such a firm is zero in the steady state. Outside the steady state, profit can be non-zero, which is rebated to the household in a lump sum and hence added to the resource side in (4), (5) and (7). Because a unit of investment costs an entrepreneur p_I units of consumption goods, the term i on the right-hand side of an entrepreneur's resource constraint, (3), is replaced with $p_I i$; the term $\pi(q-1)i$ in the household's resource constraint (7) is replaced with $\pi(q-p_I)i$; and the term $(1-\theta q)i$ in the consolidated financing constraint (4) is replaced with $(p_I-\theta q)i$. Substituting the result $p_I=1+\Psi'(I/I^*)$ yields the condition of optimal investment as

$$q-(1+\Psi')=(1+\Psi'-\theta q)\lambda^e. \tag{24}$$

Adjustment costs add two effects on optimal investment. One is on λ^e through the downpayment, $(p_I-\theta q)i$, and this effect is ambiguous analytically. On the one hand, adjustment costs prevent investment from falling by as much as in the baseline model. This has a positive effect on the downpayment on investment. One the other hand, the presence of adjustment costs allows the replacement cost of capital (p_I) to fall, which reduces the downpayment. After a negative liquidity shock, the shadow price λ^e increases by more with adjustment costs than in the baseline model if the downpayment falls by less than in the baseline model. The second effect of adjustment costs is that the marginal cost of adjustment directly enters (24). For any given (q,λ^e), the marginal benefit of investment is a decreasing function of i and the marginal cost an increasing function of i. When investment falls after a negative liquidity shock, the marginal adjustment cost falls, which reduces the replacement cost. Such savings at the margin increase the net marginal benefit of investment for any given (q,λ^e) and mitigate the upward pressure on the equity price caused by the increase in λ^e.

Although the overall effect of adjustment costs on (24) is analytically ambiguous, the effect is unlikely to overturn the positive response of the equity price to a negative liquidity shock. For the marginal savings from reduced investment to be significant, the marginal cost of adjustment, Ψ', must be sufficiently steep, which implies that the reduction in investment must be sufficiently small. This implication may be inconsistent with the observed large reduction in investment at the beginning of a recession (see Fig. 1). Moreover, for the equity price to fall with a negative liquidity shock, the savings from adjustment costs have to be so large that they wipe out the direct effect of the shock that tightens the financing constraint. This does not seem plausible.

For a concrete illustration, I set $\Psi(I/I^*)=(1/\psi)|(I/I^*)-1|^{\psi}$ and $\psi=2$. Fig. 3 depicts the responses of some variables to the negative liquidity shock examined in Section 3.2. Aggregate investment and the replacement cost of capital both fall by 5.8% on impact of the shock.[13] Despite such large savings from a lower cost of capital, the negative liquidity shock still tightens the financing constraint substantially, as depicted by the large increase in λ^e in panel b in Fig. 3, where the percentage change in λ^e is rescaled by a factor 1/100. As a result, the equity price and the bond price increase after the shock, as in the baseline model.

Panel c in Fig. 3 shows that employment and output fall by about two-third of the amounts in the baseline model on impact of the negative liquidity shock. In contrast to the baseline model, aggregate consumption falls after the shock. The reason for this

[13] With the particular function Ψ and the value $\psi=2$, the percentage deviation of p_I from the steady state is equal to that of I. This is why the two lines in panel a in Fig. 3 coincide.

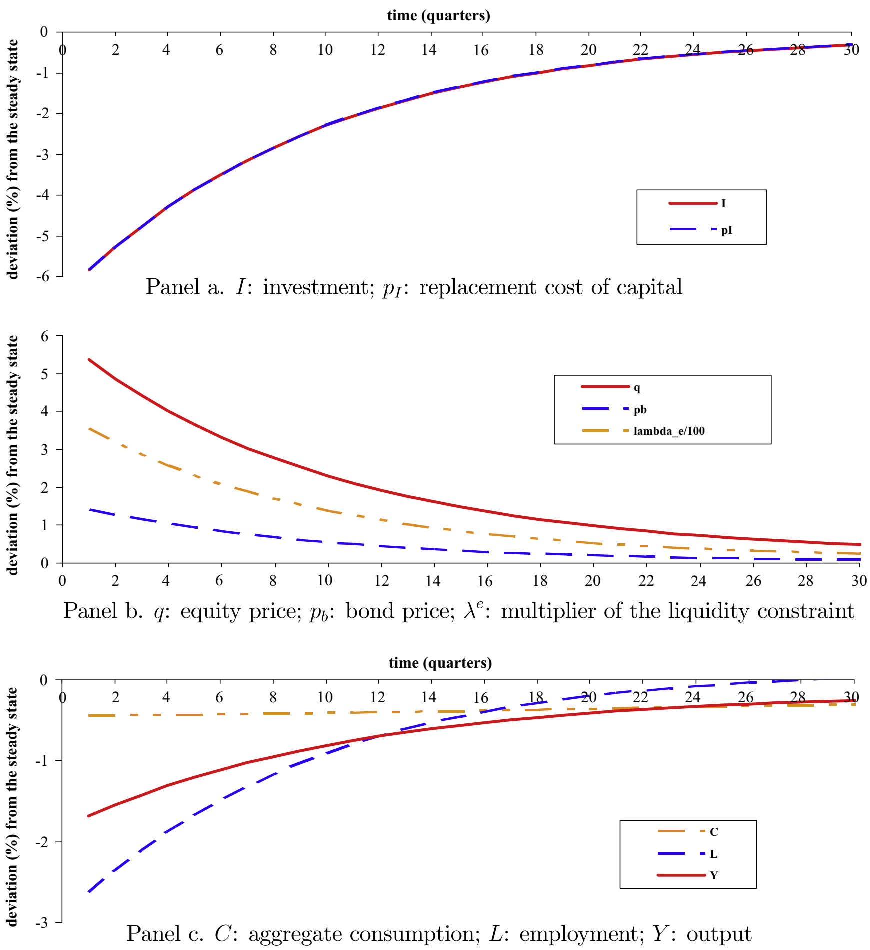


Fig. 3. Response to a negative liquidity shock with adjustment costs.

contrast is that the investment expenditure ($p_I I$) falls by 11.6%, which is less than in the baseline model. With this smaller reduction in investment expenditure, consumption also needs to fall to account for the reduction in GDP. Thus, large adjustment costs are useful for producing the positive comovement between aggregate consumption and other major macro quantities.

4. Debt finance and collateral

The analysis so far has abstracted from debt finance which can be important for the business cycle according to the literature discussed at the end of the introduction. In particular, Kiyotaki and Moore (1997) show that cyclical fluctuations in the asset value can propagate the business cycle by affecting the value of collateral. This section introduces debt finance with collateral for two purposes. One is to demonstrate that debt finance does not overturn the counterfactual response of the equity price to liquidity shocks. The other is to show that this counterfactual response extends to a broad set of financial shocks. In particular, a negative shock that reduces the borrowing capacity also increases the equity price, even when equity liquidity is fixed.

Suppose that individuals can borrow and lend through a perfectly competitive intermediary. In a period, let d^e_{+1} be the amount borrowed by an entrepreneur and d^w_{+1} the amount borrowed by a worker. Define $d_{+1} = \pi d^e_{+1} + (1-\pi) d^w_{+1}$ as the amount of borrowing per member in the household. Such borrowing among the households should be distinguished from the borrowing between the government and the households, the latter of which is still denoted b. Assume that borrowing is in the form of one-period debt. At the beginning of each period, the household pools all members' outstanding debts and divides them evenly among the members before they go to the market. During the period, each member repays the outstanding debt allocated to him. The amount of outstanding debt per member in the household at the beginning of the period is d. Let R be the gross interest rate on the outstanding debt and R_{+1} the rate on new debt.[14] For an entrepreneur, the

[14] In the equilibrium, workers are the lenders. Because a worker is indifferent between lending to the intermediary and lending to the government, the gross interest rate of lending to the intermediary must be equal to $1/p_b$. Moreover, because there is perfect competition in intermediation, the borrowing rate must be equal to the lending rate. Thus, $R_{+1} = 1/p_b$ in the equilibrium.

net receipt from new borrowing minus the repayment on the outstanding debt is $(d^e_{+1} - Rd)$, which is added to the resource side in the entrepreneur's resource constraint, (3). Similarly, the term $(d^w_{+1} - Rd)$ is added to the resource side in a worker's resource constraint, (5), and the term $(d_{+1} - Rd)$ to the resource side in a household's resource constraint, (7). The constraint on equity liquidity on an entrepreneur, (1), still applies.

The borrowing limit can depend on the asset value, as emphasized by Kiyotaki and Moore (1997). Specifically, because a borrower can renege on the repayment, a lender asks the borrower to put up collateral and is only willing to lend up to a fraction of the value of the collateral. For an entrepreneur, the collateral is equity holdings at the end of the period, whose value is qs^e_{+1}. Let $m(\phi)$ be the fraction of this value that can be collateralized, which will be referred to as the collateral multiplier. Then, an entrepreneur's borrowing limit is:

$$m(\phi)qs^e_{+1} \geq d^e_{+1}, \quad \text{where } m(\phi) \in [0,1) \text{ and } m'(\phi) \geq 0. \tag{25}$$

The case $m=0$ is the baseline model. The assumption $m<1$ captures the fact that only a part of the borrower's asset holdings are liquid and can be used as collateral. The assumption $m'(\phi) \geq 0$ captures the feature that a lender is willing to lend more if the borrower's collateral is more liquid, because the lender can sell the collateral in the market more easily in this case if the borrower defaults on the debt.[15] Although the collateral constraint is exogenously imposed here, it will be remarked later endogenizing the constraint does not change the qualitative response of the equity price to liquidity shocks.

Again, focus on the relevant case where the liquidity constraint, (1), is binding.[16] Since $m<1$, it can be verified that the collateral constraint, (25), also binds in this case. These binding constraints solve for (s^e_{+1}, d^e_{+1}). Substituting these quantities into an entrepreneur's resource constraint yields the following consolidated financing constraint on an entrepreneur:

$$\left[r+\phi\sigma q+(1-\phi)m(\phi)\sigma q\right]s+b-Rd-\tau \geq c^e+\left[1-\theta q-(1-\theta)m(\phi)q\right]i. \tag{26}$$

This constraint modifies (4) as follows. First, there is repayment on the outstanding debt, Rd. Second, the effective downpayment on each unit of investment is reduced from $(1-\theta q)$ to $[1-\theta q-(1-\theta)m(\phi)q]$. The additional reduction, $(1-\theta)m(\phi)q$, comes from the role of equity as collateral. That is, new capital created by issuing new equity can be used as collateral to secure the amount of borrowing $(1-\theta)m(\phi)q$, which reduces the cash flow needed for investment. Third, the funds from each claim on existing equity are increased from $(r+\phi\sigma q)$ to $[r+\phi\sigma q+(1-\phi)m(\phi)\sigma q]$. Again, the additional amount, $(1-\phi)m(\phi)\sigma q$, comes from the role of assets as collateral on borrowing. That is, the fraction $(1-\phi)$ of each existing equity claim that cannot be immediately sold in the market can be used as collateral to secure the amount of borrowing, $(1-\phi)m(\phi)\sigma q$.

The outstanding debt in each period is a state variable for a household, and so the value function is modified as $v(s,b,d;K,Z)$. The household's decision problem can be reformulated by adding d_{+1} as a choice, where the constraints are (9), (26), and the modified resource constraint. In the optimality conditions, (12) and (13), the term θq is replaced with $[\theta+(1-\theta)m(\phi)]q$, and the term ϕq is replaced with $[\phi+(1-\phi)m(\phi)]q$, for the reasons explained above. In the equilibrium definition, the loan market clearing condition, $d_{+1}=d=0$, is added, which comes from the fact that all households are identical.

To check the quantitative response of the equilibrium to a negative liquidity shock, the collateral multiplier is set as

$$m(\phi) = \max\{\phi+\mu(1-\phi), 0\}, \tag{27}$$

where $\mu<1$ is a constant. The assumption $\mu<1$ is imposed to guarantee $m<1$. However, $\mu \geq 0$ is not assumed. If $\mu<0$, the debt limit is lower than the value of the part of the collateral that can be immediately sold. If $\mu>0$, a borrower can borrow more than the value of this immediately liquid fraction of the collateral, possibly because a lender can sell the remaining fraction in the future. To identify μ, the micro evidence in Covas and den Haan (2011) is used, who report the ratio of debt issuance to assets and the ratio of equity sales to assets in each period for US firms. Dividing these two ratios yields the ratio of debt issuance to equity sales, denoted as DE. This ratio has large variations across firms and typically increases in firm size. The value for the bottom 50% firms, 1.287, is used as a target in order for the collateral constraint to be sufficiently binding. The parameter μ is identified by equating DE to the ratio of debt issuance to equity sales produced by the steady state of the model. Although all of the calibration targets in Table 1 are kept, incorporating the collateral role of asset holdings changes some of the equilibrium conditions and, hence, some of the parameter values. The changes in the parameter values are

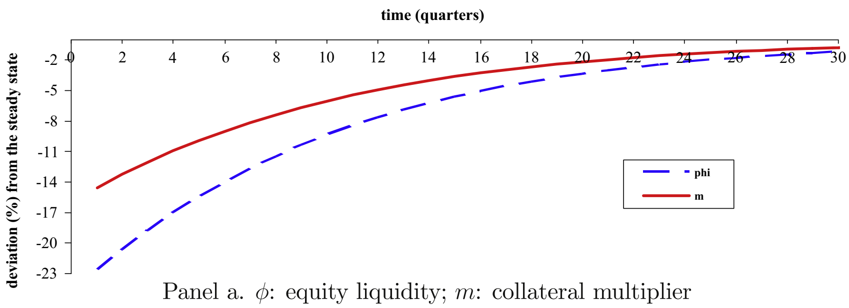
$$u_0 = 40.484, \quad h_0 = 24.078, \quad \phi^* = \theta = 0.118, \quad \mu = 0.062.$$

The implied value of the collateral multiplier is $m(\phi^*) = 0.173$.

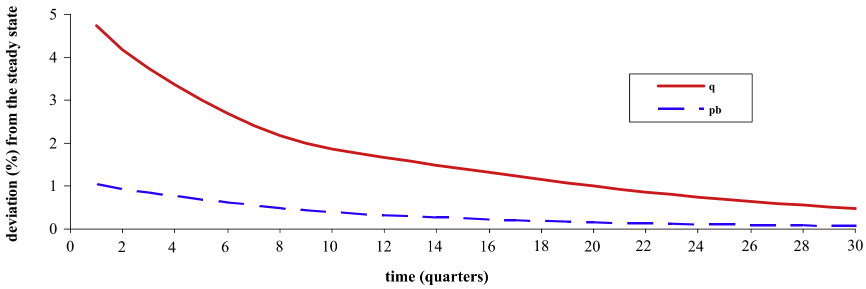
Suppose that the economy is in the steady state at $t=0$ and there is a shock at the beginning of $t=1$ that reduces ϕ from $\phi^* = 0.118$ to $\phi_1 = 0.091$. Panel a in Fig. 4 depicts equity liquidity ϕ and the collateral multiplier m. The negative liquidity shock has large and persistent effects on the collateral multiplier. On impact of the shock, the collateral multiplier falls by 14.5%. Three years after the shock, the collateral multiplier is still 5% below the steady state. Panel b in Fig. 4 depicts the prices of equity and liquid assets. As in the baseline model, a negative liquidity shock increases both prices. Also similar to the baseline model, investment and output fall (not depicted).

[15] A worker faces a similar constraint, $m(\phi)qs^w_{+1} \geq d^w_{+1}$, but this constraint is not binding, because a worker is a lender in the equilibrium.

[16] The liquidity constraint is binding in the steady state if and only if $1<q<1/[\theta+(1-\theta)m(\phi)]$, which is satisfied in the calibrated analysis below.



Panel a. ϕ: equity liquidity; m: collateral multiplier



Panel b. q: equity price; p_b: bond price

Fig. 4. Response to a negative liquidity shock with a collateral constraint.

The positive response of the equity price to a negative liquidity shock conforms with the rule of thumb described in Section 3.3. That is, by tightening an entrepreneur's financing constraint, the shock makes the resaleable portion of equity more valuable. To see why this rule of thumb still applies in the presence of debt finance, it is useful to examine the condition for optimal investment, which can be written as follows:

$$q-1=[1-\theta q-(1-\theta)m(\phi)q]\lambda^e. \tag{28}$$

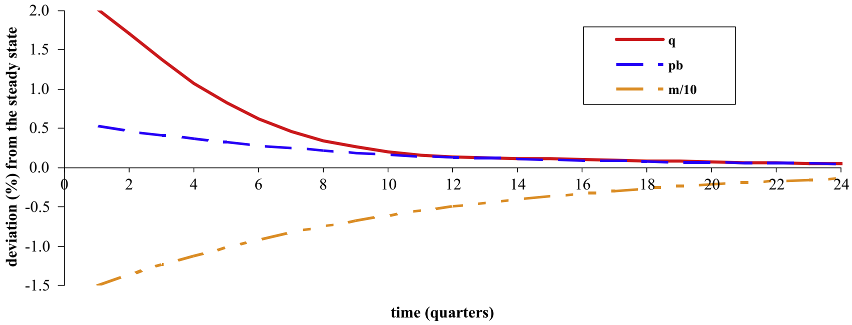
As in the baseline model, the negative liquidity shock tightens an entrepreneur's financing constraint and increases the cost of investment through λ^e. In addition, the negative liquidity shock reduces the collateral multiplier $m(\phi)$, and reduces borrowing by $(1-\theta)mq$. As the downpayment on investment increases, an entrepreneur's financing constraint is tightened further. To keep investment optimal in this case, the equity price must rise to increase the benefit of investment, $q-1$, and to mitigate the increase in the downpayment.[17]

A notable special case of the above model is $\theta=0$. In this case, an entrepreneur must finance investment entirely with debt and the receipts from selling existing assets, rather than selling new equity. Since all new equity is retained by the entrepreneur for the period in this case, it helps financing investment only as collateral on borrowing. Even in this case, a negative shock to liquidity generates an equity price boom.

It is useful to remark on the assumption $m'(\phi)\geq 0$ and the outcome of endogenizing the debt limit. First, the assumption $m'(\phi)\geq 0$ captures the intuitive feature that a reduction in equity liquidity does not increase an entrepreneur's borrowing capacity. This intuitive feature is supported by the evidence in Covas and den Haan (2011). Using micro data of US firms, they find that the ratio of debt finance to firm output is procyclical for an overwhelming majority of firms in the US. This suggests $m'(\phi)\geq 0$ if asset liquidity is procyclical. Second, because the equity price increases in response to a negative liquidity shock when $m'(\phi)=0$, continuity implies that this positive response also arises even when $m'(\phi)$ is negative and sufficiently small. Third, endogenizing the debt limit will not overturn the positive response of the equity price to a negative liquidity shock. Specifically, as long as the endogenous collateral limit has the realistic feature $m'(\phi)\geq 0$, the same mechanism as the above induces the equity price to increase after a negative shock to equity liquidity.

The collateral constraint, (25), enables me to examine other financial shocks in addition to the liquidity shock. In particular, there can be shocks to the borrowing capacity that are unrelated to equity liquidity. For example, financial development and regulations can change the amount that an entrepreneur is able to leverage against the collateral even when the liquidity of the collateral remains unchanged. Such shocks can be modeled as shocks to μ in (27). By examining how the equity price responds to such financial shocks, I hope to illustrate the generality of this response. Assume that μ

[17] The reduction in ϕ here is much smaller than in the economy without debt finance, but the responses in asset prices in the two economies are comparable in size. This is because with debt finance, the shock affects both the ability to sell equity and the ability to borrow.



q: equity price; p_b: bond price; m: collateral multiplier

Fig. 5. Response to a negative shock to the borrowing capacity.

obeys the following process:

$$-\log\left(\frac{1-\underline{\mu}}{\mu_{t+1}-\underline{\mu}}-1\right) = -(1-\delta_\mu)\log\left(\frac{1-\underline{\mu}}{\mu^*-\underline{\mu}}-1\right) - \delta_\mu \log\left(\frac{1-\underline{\mu}}{\mu_t-\underline{\mu}}-1\right) + \varepsilon_{\mu,t+1}, \tag{29}$$

where μ^* is the steady state of μ and $\underline{\mu}<1$ is the lower bound of μ. This process ensures $\mu \in [\underline{\mu}, 1)$. The identification procedure above for μ implies $\mu^* = 0.062$. Set $\underline{\mu} = -0.1$.

Consider a shock at the beginning of $t=1$ that reduces μ from $\mu^* = 0.062$ to $\mu_1 = 0.032$, while (A, ϕ) remain at their steady-state values. Fig. 5 depicts the responses of the collateral multiplier and asset prices, where the percentage deviation of the collateral multiplier from the steady state is divided by 10. Although the negative shock to μ does not affect equity liquidity, it reduces an entrepreneur's ability to borrow. On impact of the shock, the collateral multiplier falls by 15%. As the collateral multiplier falls, the prices of equity and liquid assets increase. Again, this increase in the equity price in response to the negative shock to μ can be explained with (28). By reducing the collateral multiplier, the negative shock to μ increases the downpayment on investment and, hence, increases the implicit cost of investment. In addition, by tightening the financing constraint on an entrepreneur, the negative shock increases λ^e, which further increases the implicit cost of investment. To make investment optimal, the equity price must rise to increase the benefit of investment. This positive response of the equity price to a negative shock to μ provides another illustration of the simple rule of thumb described earlier.

5. Some solutions to the problem

I have shown that the equity price increases in response to a negative shock to an entrepreneur's financing constraint, regardless of whether the shock is to the liquidity of equity or to the borrowing capacity. For the equity price to fall after such a negative financing shock, as it often does during recessions, the financing constraint must become less tight. To generate this paradoxical outcome, there must be other changes concurrent with the financing shock that sufficiently reduce the need for investment. This section discusses some candidates of these concurrent changes and relate the analysis to other attempts in the literature.

One candidate is a fall in the perceived quality of capital, which can be caused by worsening adverse selection in the asset market (e.g., Kurlat, 2013). If asset traders perceive the quality of capital to deteriorate in a recession, they will move resources from equity to relatively safe and liquid assets. This will depress the equity price and drive up the price of liquid assets. One way to incorporate this shock is to assume that the effective capital stock κK is an input in the production function, where κ is the quality of capital. With the Cobb–Douglas production function, total factor productivity is $A\kappa^\alpha$. A negative shock to the quality of capital is equivalent to a negative shock to total factor productivity.[18]

Consider a negative shock to total factor productivity, A. This shock reduces investment by reducing the marginal productivity of capital. If the shock is sufficiently persistent, then a household will also scale down consumption. These reductions in investment and consumption reduce an entrepreneur's expenditure, given by the right-hand side of the financing constraint (4). However, the negative shock to productivity may also reduce the rental income of capital, rs, which appears on the left-hand side of (4). If the reductions in investment and consumption dominate the reduction in the rental income, then the financing constraint becomes less tight and, by (23), the equity price falls.

To illustrate this possibility, return to the baseline model and introduce simultaneous shocks to ϕ and A. Suppose that the economy is in the steady state before $t=1$ and, at the beginning of $t=1$, there are unanticipated reductions in ϕ about 13% and in A about 5%. After these shocks, A and ϕ follow the deterministic dynamics of the processes in (21) and (22). Fig. 6 depicts the responses of asset prices and the Lagrangian multiplier of the financing constraint, where the percentage change

[18] One can also consider a negative shock to π–the fraction of individuals who have investment projects in a period. Again, a reasonable cause of a reduction in π is a negative shock to productivity.

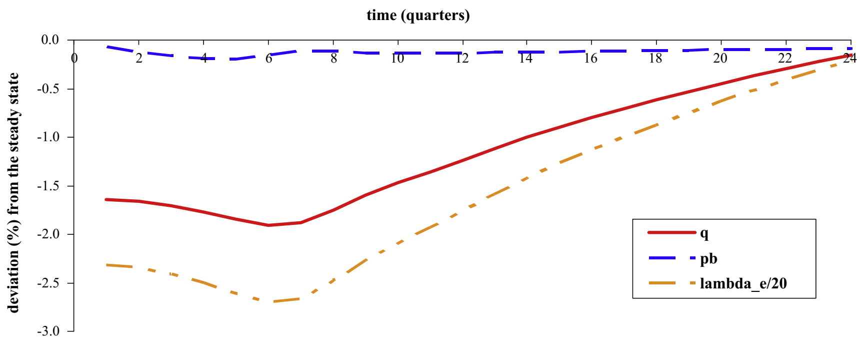


Fig. 6. Asset prices and the shadow price of the liquidity constraint after negative shocks to both productivity and liquidity.

in λ^e is rescaled by a factor 1/20. After the shocks, the equity price falls and approaches the steady state from below. Supporting the above intuitive explanation, the equity price falls because the negative productivity shock relaxes the financing constraint, as captured by the fall in λ^e.

This analysis can be related to some papers that generate a negative response of the equity price to negative liquidity shocks. The KM paper proposes two ways to resolve the problematic response of the equity price to the liquidity shock. One is to introduce a storage technology to allow entrepreneurs to shift resources between investment and storage. The analyses in Sections 3 and 4 suggest that the role of storage is limited. Regardless of whether or not a storage technology exists, the condition of optimal investment, (23), must hold. For the storage choice to change the direction of the response of the equity price, it must relax the financing constraint after a negative liquidity shock. Although this is possible with certain parameter values, it is not a realistic outcome. The other proposal is to assume that the government sells liquid assets to buy private equity in the event of a negative liquidity shock. If the injection of liquidity is sufficiently large to relax an entrepreneur's financing constraint, then the equity price can fall. In this case, liquidity injection, rather than the negative liquidity shock, is the force that drives down the equity price. This outcome is consistent with the main finding in this paper that a negative liquidity shock *alone* pushes up the equity price. Nevertheless, the outcome runs counter to the belief that liquidity injection should buttress the equity price rather than depress it.

Del Negro et al. (2011) introduce into KM an interest-rate policy rule and non-standard policy interventions as well as the elements discussed in Section 3.4, for the purpose of evaluating the US policy interventions in 2008. They show that a persistent negative liquidity shock can reduce the nominal price of equity. As in KM, the fall in the equity price is primarily driven by liquidity injection rather than the negative liquidity shock. Large injections of liquidity by the government are unlikely to be the cause of the fall in the equity price at the beginning of a recession, because these injections typically take place after the equity price has already begun to fall. Moreover, even with policy interventions, the simulation by Del Negro et al. (2011) shows only that the nominal price of equity falls after a negative liquidity shock. The real price of equity may rise. In fact, an important mechanism in their model is the interaction between nominal rigidities and the zero lower bound on the nominal interest rate under the described policy rules. The nominal price of equity falls when expected inflation falls to push the nominal interest rate close to the zero lower bound. When inflation decreases sufficiently, a fall in the nominal price of equity is consistent with a rise in the real price of equity.

Ajello (2012) incorporates into KM nominal price/wage rigidities, differentiated products and the elements discussed in Section 3.4. His emphasis is on the importance of liquidity shocks in explaining the volatility of investment and output. For the response of the equity price, the most important, new elements in his model are heterogeneity in the quality of investment among entrepreneurs and the costly intermediation to channel funds to investment. Despite all these elements, he still finds that a negative shock to ϕ increases the equity price, which is consistent with the result in Section 3.4. He then illustrates that a shock that increases the intermediation cost can reduce the equity price. By increasing the spread between the rates of return to an entrepreneur and the intermediary, the shock to intermediation affects the amount of funds that can be effectively channeled to investment and the quality distribution of investments that are undertaken in the equilibrium. As such, the intermediation shock acts as a negative shock to effective productivity, as well as to liquidity. It is then conceivable that such a negative shock can reduce the equity price.

Jermann and Quadrini (2012) use a model that differs from KM in at least the following three dimensions. First, investment is undertaken by the same firms that produce consumption goods, rather than by a separate group of entrepreneurs. Second, a firm needs working capital for all expenditures in a period, including wage payments, instead of just investment and consumption. Third, a firm faces a collateral constraint similar to (25) where the financial shock is to the collateral multiplier m directly, like the shock to μ examined in Section 4. Despite all these differences, Jermann and Quadrini (2012) find that a negative shock to m increases the equity price under the baseline calibration. They then illustrate that introducing sizable adjustment costs to investment can make the equity price fall after a negative shock to m, which contrasts the result in Section 4. Besides the differences mentioned above of Jermann and Quadrini's model from KM, an important reason for this contrast in the result is how the liquidity shock is modeled in Jermann and Quadrini (2012). They estimate a joint vector autoregression (VAR) between m and total factor productivity, whose off-diagonal elements are not zero. As a result, a negative shock to m in their model acts as combined shocks to current liquidity and future productivity. Fig. 6 illustrates that such combined shocks can reduce the equity price. Jermann and Quadrini's result is instructive in revealing the importance of the inter-dependence between asset liquidity and productivity. However, this inter-dependence itself should be explained rather than assumed in order to understand the role of liquidity shocks in the business cycle.

6. Conclusion

A tractable model is constructed to evaluate the quantitative importance of financial shocks for business cycles. The analysis has shown that a negative shock to asset liquidity or firms' collateral constraint causes aggregate investment, employment and consumption to fall with output. Although this comovement in macro quantities is realistic, the negative financial shock induces an equity price boom. This counterfactual response of the equity price is robust, provided that a negative financial shock tightens firms' financing constraints on investment. For the equity price to fall as it typically does in a recession, the negative financial shock must be accompanied or caused by other shocks that reduce the need for investment sufficiently and relax firms' financing constraints on investment. Some candidates of these concurrent shocks have been discussed.

One should take the analysis here as a constructive one, despite the negative finding. By building a tractable model to clearly identify the counterfactual response of the equity price and illustrate its robustness, this paper provides clear guidance to future research. If one wants to explain why changes in asset liquidity or the financing capacity play an important role in the business cycle, as they did in 2008, one should devote effort to endogenizing a channel through which liquidity/financial shocks affect investment quality and effective productivity, as indicated by the VAR evidence. In this regard, it may be particularly fruitful to incorporate information frictions, such as those in Chang (2010); Kurlat (2013), and Guerrieri and Shimer (2014), into dynamic stochastic general equilibrium models.

Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jmoneco.2014.10.002.

References

Ajello, A., 2012. Financial intermediation, investment dynamics and business cycle fluctuations. Manuscript, Board of Governors of the Federal Reserve System.
Bernanke, B.S., Gertler, M., 1989. Agency costs, net worth, and business fluctuations. Am. Econ. Rev. 79, 14–31.
Bernanke, B.S., Gertler, M., Gilchrist, S., 1999. The financial accelerator in a quantitative business cycle framework. In: Taylor, J., Woodford, M. (Eds.), Handbook of Macroeconomics, North-Holland, Amsterdam, pp. 1341–1393.
Chang, B., 2010. Adverse selection and liquidity distortion. Manuscript, University of Wisconsin, Madison.
Cooper, R., Haltiwanger, J., Power, L., 1999. Machine replacement and the business cycles: lumps and bumps. Am. Econ. Rev. 89, 921–946.
Covas, F., den Haan, W., 2011. The cyclical behavior of debt and equity finance. Am. Econ. Rev. 101, 877–899.
Del Negro, M., Eggertsson, G., Ferrero, A., Kiyotaki, N., 2011. The great escape? A quantitative evaluation of the Fed's non-standard policies. Manuscript, Federal Reserve Bank of New York.
Doms, M., Dunne, T., 1998. Capital adjustment patterns in manufacturing plants. Rev. Econ. Dyn. 1, 409–429.
Guerrieri, V., Shimer, R. Dynamic adverse selection: a theory of illiquidity, fire sales, and flight to quality. Am. Econ. Rev. forthcoming.
Hart, O., Moore, J.H., 1994. A theory of debt based on the inalienability of human capital. Q. J. Econ. 109, 841–879.
Jermann, U., Quadrini, V., 2012. Macroeconomic effects of financial shocks. Am. Econ. Rev. 102, 238–271.
Kiyotaki, N., Moore, J.H., 1997. Credit cycles. J. Polit. Econ. 105, 211–248.
Kiyotaki, N., Moore, J.H., 2012. Liquidity business cycles, and monetary policy. Manuscript, Princeton University.
Kurlat, P., 2013. Lemons markets and the transmission of aggregate shocks. Am. Econ. Rev. 103, 1463–1489.
Liu, Z., Wang, P., Zha, T., 2011. Land-price dynamics and macroeconomic fluctuations. NBER Working paper 17045.
Lucas Jr., R., 1990. Liquidity and interest rates. J. Econ. Theory 50, 237–264.
Nezafat, P., Slavik, C., 2010. Asset prices and business cycles with financial frictions. Social Science and Research Network, Working paper 1571754.
Shi, S., 1997. A divisible search model of fiat money. Econometrica 65, 75–102.
Shi, S., 2012. Liquidity shocks and asset prices in the business cycle. In: Allen, F., Aoki, M., Fitoussi, J.-P., Kiyotaki, N., Gordon, R., Stiglitz, J.E. (Eds.), The Global Macro Economy and Finance, Palgrave Macmillan, New York, pp. 118–130.
Shi, S., Tewfik, C. Financial frictions, investment delay and asset market interventions. J. Money Credit Bank., 2014, forthcoming.
Townsend, R., 1979. Optimal contracts and competitive markets with costly state verification. J. Econ. Theory 21, 265–293.
Williamson, S., 1987. Financial intermediation, business failures, and real business cycles. J. Polit. Econ. 95, 1196–1216.