

# Liquidity, infinite horizons and macroeconomic fluctuations

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## Abstract

This paper develops a computable dynamic general equilibrium model in which corporate demand for liquidity is endogenously determined. In the model, liquidity demand is motivated by moral hazard, as in Holmström and Tirole (1998). As a result of incorporating agency cost and endogenously determined liquidity demand, the model can replicate an empirical business cycle fact, the hump-shaped dynamic response of output, which is seldom observed in standard RBC dynamics. Further, in the model the corporate demand for liquidity from a financial intermediary (credit line, for instance) is pro-cyclical, while the degree of liquidity dependence (defined as liquidity demand divided by corporate investment) is counter-cyclical. These business cycle patterns are consistent with a stylized fact empirically verified in the *lending view* literature.

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## 1 Introduction

This paper develops a computable dynamic general equilibrium model in which the role of liquidity over the business cycles can be analyzed. My focus is especially on

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the corporate demand for liquidity and its influence on business cycles via investment decision rules. It is an empirical fact that corporations rely heavily on short-term debt for working capital expenses in the United States as well as in Japan.<sup>1</sup> Corporate finance and the role of the banking sector have recently caught considerable attention of business cycle researchers. In this stream of literature, the real business cycle (RBC) framework with a financial intermediary developed by Fuerst (1992)<sup>2</sup> is a pioneering work. It was intensively studied by Christiano (1991), Christiano and Eichenbaum (1993), and Marquis and Einarsson (2001), among others. These models are well capable of explaining empirical business cycle facts, including bank loans and other financial variables. However, they fail to replicate the actual auto-correlation patterns of output and investment.<sup>3</sup> One advantage of the model introduced in this paper is its superior performance compared with the Fuerst-Christian style of RBC models in mimicking actual auto-correlation patterns.

Another stream of studies on the interaction of corporate finance and the business cycle extends *agency cost* models, which were originally developed in microeconomic contract theory, to macroeconomics and dynamic general equilibrium analysis. Roughly speaking, the difference between the value of the firm in what would be an ideal contracting situation and what is viable through negotiation is referred to as *agency cost*.<sup>4</sup> In agency cost models, the net present value (NPV) of an investment project is not maximized, simply because lenders and borrowers (entrepreneurs) have divergent incentives, so that for each agent NPV maximization could be suboptimal. The financial contract between lender and borrower is characterized by the nature of the concessions necessary to achieve at least a second-best solution.

This study is in the stream of dynamic general equilibrium (DGE) analysis with agency cost. The key feature of my model, a unique financial contract structure, is taken from Holmström and Tirole (1998) (denoted as HT, hereafter). The paper extends the HT model to an infinite horizon environment using a modeling strategy similar to that of Carlstrom and Fuerst (1997), so that it can aid in the analysis of business cycle dynamics that result from such liquidity-dependent corporate financing. The first notable result of the paper is that my model generates a hump-shaped impulse response very similar to that in Carlstrom and Fuerst (1997), which is reported as an

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<sup>1</sup>For instance, see Einarsson and Marquis (2001).

<sup>2</sup>The theoretical foundation of the Fuerst-Christian framework is based on an earlier study by Lucas(1990).

<sup>3</sup>This is pointed out by Cogley and Nason (1995) and Gilchrist and Williams (2000).

<sup>4</sup>Amaro de Matos (2001).

empirical fact in earlier business cycle studies.<sup>5</sup>

Further, my DGE model provides several insights into other aspects of corporate liquidity demand and business cycles. Figures 1 and 2 show empirical evidence that corporate firms' working capital expenses are pro-cyclical, while the degree to which firms rely on bank loans to finance their working capital expenses, measured as the volume in commercial and industrial loans relative to output, is counter-cyclical in both the US and Japan.<sup>6</sup> My DGE model replicates this corporate financing structure over business cycles, in the sense that it successfully generates pro-cyclical demand for liquidity, while the *degree of liquidity dependence* (measured as liquidity demand divided by investment expenditure) is counter-cyclical. Moreover, this outcome exhibits clear similarity to existing empirical studies in the *lending view* literature, which claim that corporate firms become highly dependent on bank loans during recessions.

Among the existing DGE studies with agency costs, there are two studies that attempt a very similar task to my model. One is Carlstrom and Fuerst (1997) and the other is Kiyotaki and Moore (1997), both of which model infinitely lived agents with agency problems to analyze business cycle dynamics. What distinguishes my model is the structure of the financial contract.<sup>7</sup> In their models, there is no role for credit lines or corporate demand for liquidity. In contrast, since the HT style financial contract entails an explicit role for liquidity, my DGE model can analyze business cycle facts regarding corporate demand for liquidity along with dynamics of output and investment.

This paper is organized as follows. Section 2 develops the DGE model, extending a variant of the HT model to infinite horizons. Section 3 presents calibration and simulation results. Section 4 discusses some model-based interpretations of empirical facts and how they relate to *lending view* studies. I conclude the paper in section 5.

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<sup>5</sup>An empirical study of hump-shaped dynamics of output was conducted by Cogley and Nason (1995).

<sup>6</sup>For the US, I could not find the exact data for bank loans for working capital expenses. Instead, I show here total bank loans, which contain both loans for fixed business investment and other kinds of long-term financing. See Kashyap, Stein, and Wilcox (1996) and Einarsson and Marquis (2001) for more details on the empirical issue.

<sup>7</sup>The structure of the financial contract in Carlstrom and Fuerst (1997) is taken from Townsend (1979) while that of Kiyotaki and Moore is from Hart and Moore (1994).

## 2 The dynamic general equilibrium model with corporate demand for liquidity

### 2.1 Overview

Consider a two-good economy consisting of a continuum of agents with unit mass. The agents are of two types. A fraction  $\eta$  of the population consists of entrepreneurs (firms) and the rest is composed of consumers (households). The two goods are capital and consumption goods. Capital is produced from consumption goods using constant-return-to-scale technology that is specific to the entrepreneurs. This capital producing process takes place under moral hazard as described in detail in the following subsection. The economy is also populated with many firms producing a single consumption good. I refer to them as *retailers* to distinguish them from entrepreneurs. Retailers are assumed to be free from moral hazard, and so I need not specify how they are financed. They produce consumption goods at the level at which price equals marginal cost. In addition to these three agents, there is a financial intermediary in the economy. The financial intermediary is not an optimizing agent, but rather a mechanical function whose role will be discussed in detail later.

The sequence of events in each period is described as follows. At the beginning of each period, the aggregate productivity shock to retailers is realized and everyone knows the current level of the capital price  $q_t$  and the entrepreneurs' net worth  $n_t$ . Retailers hire labor and rent capital from consumers and entrepreneurs, and then produce consumption goods at a given  $q_t$  and  $n_t$ . Consumers sell their capital to the financial intermediary and purchase consumption goods produced by retailers. Then, they decide how much to consume and save. The financial intermediary collects the consumers' savings (consumption goods). Further, the financial intermediary implements the optimal financial contract with the entrepreneurs and provides them with the necessary initial input of consumption goods. The rest of the consumption goods are kept by the financial intermediary for additional needs of entrepreneurs due to idiosyncratic "liquidity shocks." The idiosyncratic liquidity shock to each entrepreneur is realized, and some projects facing large liquidity shocks are abandoned. Entrepreneurs whose projects are not abandoned due to liquidity shocks make decisions about their effort level. At the end of the production process, those projects that are not abandoned yield capital goods. The financial intermediary collects the newly produced capital and distributes it to the consumers.

This is a substantial modification of the standard RBC where there is an *ex-post* one-

to-one technology for transforming consumption goods into capital. In the standard RBC model, a unit input of consumption goods is transformed into one unit of capital at the end of the period. In such an environment, it does not make sense to distinguish capital from consumption goods, and the price of capital is always equal to one. Hence, the RBC models are basically regarded as a one-good economy.

In the economy presented here, entrepreneurs receive external funds and credit lines via the financial intermediary. Essentially, the role of the intermediary here is to assure a certain return to consumers by providing entrepreneurs with collected consumption goods either as initial inputs or as additional credit lines. Consumers who sold units of consumption goods at the beginning of the period will receive  $1/q_t$  unit of capital from the intermediary at the end of the period. Because of this deterministic return over the duration of the financial contract, consumers are regarded as effectively risk neutral in terms of the financial contract. In the following subsections, I will rely on this property to distinguish issues regarding intra-period financial contracts from the inter-temporal optimization of consumers and entrepreneurs.

## ***2.2 Intra-period financial contracts and corporate liquidity demand***

First, I describe the financial contract between entrepreneurs and consumers, introducing the model of corporate liquidity demand presented by HT (1998) in a slightly modified fashion. Since the financial contract is only one period in length, I can consider the financial contract and investment behavior separately from the rest of the dynamic general equilibrium. In this subsection, I omit the time subscript  $t$  for the capital price  $q_t$ , firms' net worth  $n_t$  and other variables for simplicity.

Corporate liquidity demand is motivated by moral hazard. HT's (1998) arguments are summarized as follows. The entrepreneur must be given a minimum share of profit in order to be motivated to invest. Because of this, the value of external claims on the firm is necessarily less than the full value of the firm. The gap between the full value of the firm and the external value of the firm prevents it from financing all projects that have positive net present value. This implies that liquidity shocks could force the firm to terminate a project midstream, even though the project has a positive continuation value. To avoid such risks, the firm may want to hold either liquid reserves in the form of marketable assets that can be readily sold or credit lines provided by the financial intermediaries.

HT also demonstrate that, in the absence of aggregate uncertainty, the financial intermediary can achieve production efficiency in the sense that privately issued liquid

assets (including credit lines) are sufficient for insurance.<sup>8</sup> I will rely on this result later in embedding the financial contract into the dynamic general equilibrium model.

The moral hazard model shown here is essentially identical to that of HT, except for two minor modifications. One is that everything is going on within a single period, while the original HT model is a three-period model. I can reconcile the difference by implicitly regarding each period as segmented into three sub-periods. The other is that capital goods are distinguished from consumption goods. The end-of-period capital price is  $q$  in terms of consumption goods. The financial contract is negotiated in the beginning of each period and is resolved by the end of that same period. General equilibrium issues affect the contract only through the level of firms' net worth,  $n > 0$ , and price of capital,  $q > 0$ .

Firms (entrepreneurs) and households (consumers) are assumed to be risk neutral.<sup>9</sup> A firm has access to a stochastic constant-returns-to-scale technology to convert an amount  $i$  of consumption goods into  $Ri$  of capital. In the middle of a given period, an additional uncertain amount of consumption goods input is necessary to cover working capital expenses and other cash needs. I assume that this uncertain amount of "liquidity shock" is proportional to planned capital output  $Ri$  and hence can be written as  $\tilde{\omega}Ri$ .<sup>10</sup> There is no loss of generality in redefining  $\tilde{\omega}R \equiv \omega$  due to linearity. The redefined liquidity shock  $\omega$  is distributed according to the cumulative distribution function  $\Phi(\omega)$  with a density  $\phi(\omega)$ . If  $\tilde{\omega}Ri = \omega i$  is paid, the project continues and a final pay-off is realized. If  $\omega i$  is not paid, the project terminates and yields nothing. The larger is the value of the entrepreneur's investment project, the more additional input is required midstream to prevent the project from being abandoned.

Investment is subject to moral hazard in that a firm (entrepreneur) privately chooses

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<sup>8</sup>See proposition 2 in HT. Interestingly, the proposition reveals that full insurance cannot be achieved by financial market trading. Only financial intermediation can provide risk sharing by pooling idiosyncratic risks. Therefore, it is important to incorporate the financial intermediary as the *fourth* agent in my dynamic general equilibrium model here.

<sup>9</sup>Later in section 2.3, consumers turn out to be risk averse, since their utility is concave. However, in terms of the financial contract, they will be effectively risk neutral. Carlstrom and Fuerst (1997) denote two conditions that are sufficient for risk neutrality: (i) there is no aggregate uncertainty over the duration of the contract, and (ii) the financial intermediary can take advantage of the law of large numbers to eliminate idiosyncratic risks. These two properties allow the financial intermediary to assure a deterministic return to consumers. Due to this property, those risk-averse consumers can be treated as if they are risk neutral. I will refer to this issue again in section 2.3.

<sup>10</sup>This proportionality is necessary to maintain tractability of the model, so that the break-even condition holds with equality.

the probability  $\pi$  that the project succeeds. The firm can either “behave” or “shirk”. If the firm behaves, the probability of success is  $\pi_H$  (high): if it shirks, the probability of success is  $\pi_L$  (low), where  $\pi_H - \pi_L \equiv \Delta\pi > 0$ . If the firm shirks, it enjoys a private benefit,  $Bi > 0$ , proportional to the level of initial investment  $i$ . The firm makes the decision about its effort level,  $\pi_H$  or  $\pi_L$  after the continuation decision.

The net present value of the investment is maximized by continuing the project if and only if  $\omega \leq \omega_1 \equiv \pi_H R$ , that is, whenever the expected return  $\pi_H R$  from continuation exceeds the cost  $\omega$ . HT refers to this  $\omega_1$  as the *first-best cut off*.<sup>11</sup> The firm has an endowment of net worth,  $n (> 0)$ , at the beginning of the period and can raise additional funds from outside investors. A contract with outside investors specifies the amount that the investors will contribute  $i - n$ , the initial scale of the project  $i$ , the contingencies under which the project will be continued at the emergence of liquidity shock (the cut-off level of liquidity shock  $\bar{\omega}$ ), and the distribution of the profit from the investment. Let  $R_f i$  be the amount that the firm is to be paid when the project succeeds. Generally  $R_f$  can be contingent on  $\omega$ , but the second-best contract is achieved by a contract such that the incentive compatible constraint,  $\pi_H R_f \geq \pi_L R_f + B$ , is binding. That is, the entrepreneur’s share of profit is bounded by a minimum level that prevents it from shirking. With the binding incentive compatibility constraint,  $R_f = B/\Delta\pi$ , outside investors’ expected cash flow excluding the liquidity shock, is  $\pi_H (R - R_f) \equiv \omega_0$ .  $\omega_0$  is called the *pledgeable unit return* from investment.

Now I am ready to set up the optimal financial contract problem to choose  $\{i, \bar{\omega}, R_f(\omega)\}$ .

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<sup>11</sup>They assume

$$\begin{aligned} & \int \max \{ \pi_H R - \omega, 0 \} \phi(\omega) d\omega - 1 \\ & > 0 \\ & > \int \max \{ \pi_L R + B - \omega, 0 \} \phi(\omega) d\omega - 1, \end{aligned}$$

so that they could concentrate on contracts that implement the effort  $\pi_H$ .

$$\begin{aligned}
\max \quad & : \quad qi\pi_H R_f \int_0^{\bar{\omega}} \phi(\omega) d\omega \\
& = \quad qi\pi_H R_f \Phi(\bar{\omega}) \\
\text{s.t.} \quad & i - n \leq q \left[ i \int_0^{\bar{\omega}} (\pi_H (R - R_f) - \omega) \phi(\omega) d\omega \right] \\
& = \quad qi \left[ \omega_0 \Phi(\bar{\omega}) - \int_0^{\bar{\omega}} \omega \phi(\omega) d\omega \right] \\
& \equiv \quad qih(\bar{\omega}) \tag{1}
\end{aligned}$$

$$R_f \geq R_f^{low} = \frac{B}{\pi_H - \pi_L} \tag{2}$$

The problem is to maximize a firm's share of profit subject to outside investors' break-even constraint eqn (1) and the firm's incentive compatible constraint eqn (2). With the incentive compatible constraint binding, the remaining choice is  $i$  and  $\bar{\omega}$ . Since everything is linear in the problem, the break-even condition must hold with equality. This yields the following relation:

$$i = \left( \frac{1}{1 - qh(\bar{\omega})} \right) n. \tag{3}$$

Substituting this into the objective function leaves an unconstrained problem with respect to  $\bar{\omega}$ .

$$\max_{\bar{\omega}} : \left( \frac{q\Phi(\bar{\omega})}{1 - qh(\bar{\omega})} \right) \pi_H R_f n \tag{4}$$

Using partial integration,  $h(\bar{\omega})$  can be rewritten as follows.

$$h(\bar{\omega}) = \omega_0 \Phi(\bar{\omega}) - \int_0^{\bar{\omega}} \omega \phi(\omega) d\omega \tag{5}$$

$$= (\omega_0 - \bar{\omega}) \Phi(\bar{\omega}) + \int_0^{\bar{\omega}} \Phi(\omega) d\omega \tag{6}$$

Paying attention to the derivative  $h'(\bar{\omega}) = (\omega_0 - \bar{\omega}) \phi(\bar{\omega})$ , the first order condition of eqn (4) is

$$q \int_0^{\bar{\omega}} \Phi(\omega) d\omega = 1. \tag{7}$$

Based on the closed form, I can define an implicit function of the optimal cut-off level of liquidity shock,  $\bar{\omega} = \psi(q)$ . Plugging this into eqn(3), I obtain an individual investment

function in the following form;

$$\begin{aligned} i &= \left( \frac{1}{1 - qh(\psi(q))} \right) n \\ &\equiv k(q) n. \end{aligned} \tag{8}$$

Thus individual investment is linear in  $n$  with a factor of proportionality of  $k(q)$ , which exceeds one. HT call  $k(\cdot)$  the *equity multiplier*. Note that very similar multipliers to this  $k(\cdot)$  can be found in many other models with agency cost.<sup>12</sup> In fact, it is a peculiar and common feature of those imperfect information models that investment requires a *down payment*. It can be shown that the investment function, eqn(8), is upward sloping in the capital price  $q$  just as the investment function of the adjustment cost model is increasing in the shadow price of capital. A significant difference is that eqn(8) is not only a function of  $q$ , but also of the firm's net worth  $n$ , which will be the key feature in generating unique dynamics in an infinite horizon extension.

Finally, I introduce *aggregate* corporate liquidity demand  $D$  and the “degree of liquidity dependence”  $x$ , which is defined as aggregate liquidity demand divided by aggregate investment output  $I$  for a later purpose in the empirical discussion.

$$D = \eta qi \int_0^{\bar{\omega}} \omega \phi(\omega) d\omega \tag{9}$$

$$x = \frac{D}{qI} = \frac{\int_0^{\bar{\omega}} \omega \phi(\omega) d\omega}{\Phi(\bar{\omega}) \omega_1} \tag{10}$$

where aggregate investment output  $I = \eta i \omega_1 \Phi(\bar{\omega})$  instead of  $\eta \omega_1 i$ , since the fraction ( $= 1 - \Phi(\bar{\omega})$ ) of investment projects whose liquidity shocks are larger than  $\bar{\omega}$  are abandoned.

### 2.3 *The role of the financial intermediary and risk-averse consumers*

One of HT's fundamental questions is whether a privately issued liquid asset would be sufficient for achieving the second-best outcome described above. In the absence of aggregate uncertainty (idiosyncratic risk for each entrepreneur is independent), the answer is yes. I assume that there is a continuum of entrepreneurs in the economy. Thanks to the constant-returns-to-scale technology, there is no loss in assuming that entrepreneurs have identical net worth; the representative entrepreneur is endowed with  $n$  units of net worth at the beginning of the period. Then, the additional liquidity

<sup>12</sup>For example, see Bernanke and Gertler (1989), Bernanke, Gertler and Gilchrist (2001), Carlstrom and Fuerst (1997) and Kiyotaki and Moore (1997).

needs,  $D$ , demanded by the whole productive sector are defined as in eqn (9),  $D = \eta qi \int_0^{\bar{\omega}} \omega \phi(\omega) d\omega$ , where  $i$  is the representative firm's investment. Since the price of capital is realized at the beginning of a period and remains constant all through the period, it can be regarded as a constant parameter that is common to every agent in the economy.<sup>13</sup> Further, by taking advantage of the law of large numbers, it turns out that this amount,  $D$ , is a deterministic number. On the other hand, the maximum amount of the claims for the existing firms is equal to  $\eta qi \omega_0 \Phi(\bar{\omega}) \equiv V$ . Reflecting the individual condition in eqn(1), it can be shown that

$$\begin{aligned} V - D &= \eta qi \left[ \omega_0 \Phi(\bar{\omega}) - \int_0^{\bar{\omega}} \omega \phi(\omega) d\omega \right] \\ &= \eta(i - n) > 0. \end{aligned}$$

Hence, there is a sufficient number of privately issued claims to meet firms' additional liquidity demands. I now incorporate the fourth agent, the financial intermediary.<sup>14</sup> The financial intermediary collects all of the consumption goods and offers credit lines up to  $q\bar{\omega}i$  for each entrepreneur so that the second-best financial contract described above can be implemented. The law of large numbers allows the intermediary to grant  $D$  of funds to entrepreneurs in total. As a result of each entrepreneur's production with the credit line up to the second-best cut off, the entrepreneurial sector as a whole can produce  $V$  of capital at the end of the period.

Essentially, the role of the financial intermediary in this economy is *risk pooling* to achieve insurance. HT demonstrates that there can be many variants of this kind of financial intermediary in the real world. Any variant that can offer credit lines to entrepreneurs are sufficient for the purpose.

Having confirmed that the intra-period idiosyncratic risks are completely eliminated in the economy, I now discuss the validity of the assumption of risk neutrality for con-

<sup>13</sup>In the following section, a dynamic general equilibrium analysis, it will be shown that the capital price  $q$ , which is in eqn(9), is stochastic and time-variant. However, in terms of the intra-period financial contract, note that  $q$  is a deterministic parameter, since  $q$  is known before the contract is written and remains constant during the contract period.

<sup>14</sup>Carlstrom and Fuerst (1997) refer to this financial intermediary as a "Capital Mutual Fund" (CMF). This notion was first incorporated by Williamson (1986). It should be emphasized that the notion of "mutual fund" referred to in the HT model is a different concept. The HT's "mutual fund" has no risk pooling function. Actually, HT admits that their "mutual fund" cannot achieve production efficiency, and thus it is not classified as a kind of intermediary. Essentially, what distinguishes *the* intermediary here from other financial institutions is the ability to offer credit lines to entrepreneurs. Note that the value of marketable claims held by a firm cannot be made contingent on that firm's idiosyncratic shock. Risk pooling can be implemented only via credit lines.

sumers. In section 2.2, I assume that consumers are risk neutral in terms of the financial contract following the original HT model. But, as shown in the next section, it turns out that consumers have concave utility functions and thus they are actually risk averse. To reconcile the two seemingly contradictory natures of consumers, it is necessary to confirm that the intra-period financial contract problem and inter-temporal optimization can be separated. Essentially, since everything is deterministic in the duration of the financial contract, risk-averse consumers can be regarded as effectively risk neutral in terms of the financial contract. The following three key factors are important to understand why the intra-period problem can be separately considered from inter-temporal optimization.

The first factor is the length of the financial contract. In each period, the financial contract is made at the beginning and resolved at the end of the period. By assuming sufficient inter-period anonymity, the history of each agent cannot affect the financial contract in each period. The second factor is the law of large numbers and the role of the financial intermediary. As discussed above, thanks to the role of the financial intermediary, idiosyncratic risk cannot be a source of aggregate uncertainty. The final factor is the most important, namely, the timing of events. As discussed in section 2.1, aggregate technology shock is realized at the very beginning of a period. After the technology shock is revealed, there will be no additional information during the period. This is why the price of capital is also determined immediately after the realization of the technology shock. It should be noted that the current levels of capital price and aggregate technology are known by everyone *before* the financial contract is written, and these remain unchanged during each contract period. (Note that the end-of-period value of capital at period  $t$  is  $q_t K_{t+1}$ , where  $K$  denotes capital stock measured by capital goods.) Due to the order of events, clearly neither capital price nor technology shock can be a source of aggregate uncertainty in terms of a financial contract. These three key factors together make the intra-period capital market return deterministic at any given  $q_t$  and current technology level regardless of how they are determined.<sup>15</sup>

A remaining question concerning the capital producing process is how the current price of capital,  $q_t$ , is determined. In this economy, everyone knows that in the future the financial intermediary will eliminate idiosyncratic risk completely in each period.

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<sup>15</sup>Carlstrom and Fuerst (1997) present a similar argument regarding this matter. In their model, financial constraint is characterized by the agency problem with costly monitoring where “risk-neutral” consumers are introduced as lenders of funds to entrepreneurs. By adopting nearly identical structures/assumptions to those in the model in this paper, these authors treat risk-averse consumers as risk neutral in terms of intra-period financial contracts. See Carlstrom and Fuerst (1997) for more details.

The only aggregate uncertainty comes from future technology shocks and future capital prices, but they are pure inter-period uncertainties that do not affect the consequences of the intra-period financial contracts, as we have already discussed. The price of capital is determined by the intertemporal efficiency conditions of the economy in a similar fashion to that of Tobin's  $Q$  in adjustment cost models of investment. I will show the intertemporal efficiency condition in the following section.

## 2.4 Efficiency conditions

### 2.4.1 Consumers

The consumers' problem is standard. They maximize an infinite sum of discounted utility from consumption,  $(c_t)$ , and labor supply,  $(l_t)$ .

$$\max : U^c = E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, l_t) \quad (11)$$

where  $\beta$  is a discount rate. At the beginning of each period, they lend previously accumulated capital ( $k_t^c > 0$ ) at a rental rate  $r_t$ , and supply their labor force at a wage rate  $w_t$ . After obtaining consumption goods from retailers (in return for  $k_t^c$  sold to the financial intermediary), they make a consumption-savings decision. Their savings, which are in terms of consumption goods, are collected by the financial intermediary. At the end of each period they will be given  $1/q_t$  units of newly produced capital (measured in consumption goods) for each unit of savings input. As I discussed, this deterministic capital market (gross) return allows us to regard those risk-averse consumers as effectively risk neutral in terms of financial contracts. Consumers' inter-temporal flow of funds can be written as follows;

$$q_t k_{t+1}^c = q_t (1 - \delta) k_t^c + r_t k_t^c + w_t l_t - c_t,$$

where  $k_t^c$  and  $\delta$  denote individual consumers' capital holdings and depreciation rate of capital. Consumers' optimal conditions are summarized as follows.

$$\begin{aligned} -\frac{u_{l,t}}{u_{c,t}} &= w_t \\ E_t \beta \left( \frac{q_{t+1} (1 - \delta) + r_{t+1}}{q_t} \right) \frac{u_{c,t+1}}{u_{c,t}} &= 1. \end{aligned}$$

### 2.4.2 *Entrepreneurs*

Entrepreneurs are risk neutral. They maximize an infinite sum of discounted consumption  $c_t^e$ . Because of the moral hazard discussed above, the return on internal funds is higher than that on external funds. This higher return on internal funds induces entrepreneurs to postpone their consumption forever, and thus the economy never reaches a steady state. To avoid oversavings of entrepreneurs, their discount factor  $\gamma\beta$  is assumed to be smaller than that of consumers:  $\gamma\beta < \beta$ .<sup>16</sup> The entrepreneurs' optimization is written as follows.

$$\begin{aligned}
 \max \quad & : \quad U^e = E_0 \sum_{t=0}^{\infty} (\gamma\beta)^t c_t^e \\
 \text{s.t.} \quad & q_t k_{t+1}^e = (1 + \rho_t) n_t - c_t^e \\
 \text{where,} \quad & n_t = (1 - \delta) q_t k_t^e + r_t k_t^e + w_t^e \\
 & 1 + \rho_t = \frac{q_t \pi_H R_f \Phi(\bar{\omega}_t)}{1 - q_t h(\bar{\omega}_t)} \tag{12}
 \end{aligned}$$

where  $k_t^e$ ,  $n_t$ , and  $\rho_t$  denote an individual entrepreneur's capital, net worth and net return rate respectively.  $w_t^e$  is a wage rate for entrepreneurs' labor supply, which is fixed at one. This labor income assures a positive net worth of entrepreneurs. Entrepreneurs invest the whole  $n_t$  at the beginning of a period to receive its return  $q_t \pi_H R_f \Phi(\bar{\omega}_t)$  at the end of the period. Since  $i_t = n_t / \{1 - q_t h(\bar{\omega}_t)\}$  as shown in eqn(3), the return rate  $\rho_t$  is defined as in eqn(12). Using this notation, the entrepreneurs' Euler equation can be written as

$$q_t = E_t \beta \gamma (q_{t+1} (1 - \delta) + r_{t+1}) (1 + \rho_{t+1}). \tag{13}$$

It should be noted that net worth does not appear in this equation, so that this condition holds for any level of net worth.

As for the efficiency condition eqn(13), the price of capital is determined so that eqn(13) is satisfied for each period. Combined with a transversality condition, eqn(13) can be solved numerically, although there does not exist an explicit solution form. But conceptually,  $q_t$  is the present value of marginal products adjusted by the future agency costs. To clarify this idea, suppose that  $\rho_t$  is constant for the future. Then, eqn(13)

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<sup>16</sup>Another technique to avoid negative consumption by entrepreneurs is to simply assume that they consume a certain amount of wealth in each period. I can interpret this as meaning that a certain fraction of the entrepreneurs die in each period. This type of assumption is made in Kiyotaki and Moore (1997) for example.

can be rewritten as follows;

$$q_t = E_t \sum_{j=0}^{\infty} \{\beta\gamma(1 + \rho)\}^{j+1} (1 - \delta)^j r_{t+j+1}.$$

By assumption, this solution form is a rough approximation for the true one because of the time-invariant  $\rho_t$  ( $= \rho$ ). In the true solution, which is highly nonlinear, a part of the discount factor  $\rho_{t+j}$  fluctuates endogenously, reflecting the agency cost at each period.

### 2.4.3 Retailers

The retailers' problem is again standard. Their production function is one of constant return to scale, such that  $Y_t = v_t F(K_t, L_t, H_t)$ , where  $K_t, L_t$  and  $H_t$  denote aggregate capital, labor input from consumers and labor input from entrepreneurs, respectively.  $v_t$  is a random productivity shock that is normalized at one in a steady state. Since retailers are free from moral hazard, their production always takes place at the efficient level of input, so that  $r_t = v_t F_K(K_t, L_t, H_t)$ ,  $w_t = v_t F_L(K_t, L_t, H_t)$  and  $w_t^e = v_t F_H(K_t, L_t, H_t)$ .

## 2.5 Equilibrium

The equilibrium of the economy is defined as the set of  $K_{t+1}, k_{t+1}^e, H_t, L_t, l_t, n_t, i_t, c_t^e, c_t, q_t, x_t, I_t, D_t, w_t, r_t$ , and  $\bar{w}_t$  which satisfies the following decision rules for each agent and optimal financial contract (eqn 13-19), resource constraints (eqn 20-23) and

exogenous state transition (eqn 24).

$$u_{c,t} = E_t \beta \left( \frac{q_{t+1}(1-\delta) + r_{t+1}}{q_t} \right) u_{c,t+1} \quad (14)$$

$$w_t = -\frac{u_{l,t}}{u_{c,t}} \quad (15)$$

$$q_t = E_t \beta \gamma (q_{t+1}(1-\delta) + r_{t+1}) (1 + \rho_{t+1}) \quad (13)$$

$$i_t = \left( \frac{1}{1 - q_t h(\bar{\omega}_t)} \right) n_t$$

$$D_t = \eta q_t i_t \int_0^{\bar{\omega}_t} \omega \phi(\omega) d\omega$$

$$I_t = \eta \Phi(\bar{\omega}_t) \omega_1 i_t \quad (16)$$

$$\bar{\omega}_t = \psi(q_t)$$

$$x_t = \frac{D_t}{q_t I_t} \quad (17)$$

$$r_t = v_t F_K(K_t, L_t, H_t) \quad (18)$$

$$w_t = v_t F_L(K_t, L_t, H_t) \quad (19)$$

$$Y_t = (1 - \eta) c_t + \eta i_t \left( 1 + q_t \int_0^{\bar{\omega}_t} \omega \phi(\omega) d\omega \right) + \eta c_t^e \quad (20)$$

where,  $Y_t = v_t F(K_t, L_t, H_t)$

$$L_t = (1 - \eta) l_t \quad (21)$$

$$K_{t+1} = (1 - \delta) K_t + I_t \quad (22)$$

$$k_{t+1}^e = \frac{1}{q_t} \{ (1 + \rho_t) n_t - c_t^e \} \quad (23)$$

where,  $n_t = w_t^e + k_t^e (q_t(1 - \delta) + r_t)$

$$v_{t+1} = \sigma v_t + (1 - \sigma) v^* \quad (24)$$

Some remarks are in order. Eqn(20) denotes consumption goods market clearing condition. Eqn(23) describes an entrepreneur's capital accumulation. Productivity shock is specified as AR(1) as shown in eqn(24), where  $v^*$  denotes the normalized steady state level of productivity.

## 3 Simulations

### 3.1 Calibration

Let us start with the entrepreneurs' technology. I assume a uniform distribution  $[0, 2]$  for liquidity shocks as a benchmark. This distribution implies that the initial unit of investment requires the same amount of working capital expenses as the mean.<sup>17</sup> Following a standard RBC environment, consumption goods are converted into capital via a one-to-one transformation technology. That is, total expected return from unit investment ( $= \omega_1 \Phi(\omega_1)$ ) is set at unity so that the technology of the entrepreneurial sector as a whole is a one-to-one transformation in the presence of perfect information. Note that even in the case with symmetric information, a fraction  $(1 - \Phi(\omega_1))$  of investment is abandoned because of liquidity shocks. Given the uniform distribution, this one-to-one technology gives us  $\omega_1$  set equal to 1.414. With the imperfect information in the economy, this technology does not assure the full return, since a portion of the return disappears due to the agency cost. In this sense, the unpledgeable part of the profits, which is given to the entrepreneurs due to the incentive compatibility constraint, is the most important parameter to calibrate. As HT (1998) argue in their paper, where there is no moral hazard in the capital production process ( $B = 0$  or  $\omega_1 = \omega_0$ , equivalently), entrepreneurs do not demand any liquidity, since the moral hazard is the essential motivation for advance financing. It should be emphasized that in a special case of my DGE model, where  $\omega_1$  is set equal to  $\omega_0$  (the entrepreneur's share of the profit is zero), my DGE model collapses to the standard RBC model. Here, as a tentative value, I set  $\omega_0/\omega_1 = 0.75$ , which implies that, on average, 25% of the profit are given to the entrepreneur. As this value is purely ad-hoc, I will later examine how sensitive the model is to this value. Given these parameter settings, the ex-post capital production out of unit input ( $= \omega_1 \Phi(\bar{\omega})$ ) is 0.987 in the steady state, which implies that about 1.2% of resources are lost during the capital production process as the result of agency cost.

For most of the other parameters and functional forms, I follow Carlstrom and Fuerst (1997). The consumers' utility is additively separable in consumption and labor, such that  $U(c_t, l_t) = \left( c_t^{1-\theta} / 1 - \theta \right) + \mu(1 - l_t)$ , where  $\theta$  is set at 1.5. As for  $\mu$ , it is chosen so that steady state labor supply is 0.3. Consumption goods' production is Cobb-Douglas, such that  $F(K_t, L_t, H_t) = v_t K_t^\alpha L_t^{1-\alpha-\alpha'} H_t^{\alpha'}$ , where  $\alpha$  is 0.3 and  $\alpha'$  is 0.01. Discount rates are  $\beta = 0.99$  and  $\gamma = 0.95$ .

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<sup>17</sup>In the following subsection I will examine alternative values for this mean (or the upper bound) of the uniform distribution, for sensitivity analysis.

I am left with three parameters:  $\eta$  which represents the proportion of entrepreneurs in the population;  $\delta$ , depreciation rate of capital; and  $\sigma$ , the AR(1) coefficient for productivity shock. As a tentative value  $\eta$  is set at 0.3, which implies that 30% of the population are entrepreneurs. For  $\delta$  and  $\sigma$ , I choose 0.025 and 0.9 following typical RBC studies such as King et al. (1988).<sup>18</sup>

## 3.2 *Simulation results*

### 3.2.1 *Impulse response to a productivity shock*

The solution technique that I utilize here is the standard undetermined coefficient method (the Eigen decomposition method). Simulations are based on a log-linearized model around the steady state of the non-stochastic part of the system.

I report the simulation results in Figures 3-5. The figures show the response of my “liquidity model” (denoted as the “LI” model hereafter) to a positive productivity shock. For comparative purposes, the impulse response of the standard RBC model<sup>19</sup> is presented in each panel. The notable feature of the LI model is the hump-shaped response of output as shown in the upper panel in Figure 3. This is in sharp contrast to the familiar RBC dynamics, that is, investment and output increase sharply on impact and begin to decrease immediately thereafter. Cogley and Nason (1993, 1995) demonstrate the dynamics of output (also labor hours and investment) of the RBC model inherited from the auto-correlation structure of the productivity shock. Since the productivity shock is assumed to be AR(1), the output dynamics of the RBC model accordingly show a sharp rise followed by a steady decline. The key variable generating this contrast between the two models is the behavior of the entrepreneurs’ net worth. Recall that the entrepreneurs’ net worth is a combination of capital and wage/rental income. Although their income can jump up to a stable path, their capital cannot, since it is a state variable. Because of this, the initial response of net worth is limited. Similarly, the entrepreneur’s investment is a function of capital price and net worth, which necessarily means that investment is driven up by an initial increase in capital price, although the extent of such a jump is limited, since net worth is nearly fixed on impact. Cogley and Nason (1995) and Carlstrom and Fuerst (1997) report that output dynamics observed in actual US time series data is consistent with this hump-shaped

<sup>18</sup>Carlstrom and Fuerst (1997) choose a slightly more persistent value of 0.95 for  $\sigma$ .

<sup>19</sup>Recall that the RBC model is a special case of the LI model where parameters are chosen such that  $\omega_1 = \omega_0$ . This is a perfect information environment.

pattern of behavior. The intuitive economic explanation of this hump-shape is as follows. At the initial shock of increased productivity, the firm finds that its investment is now more profitable, but actual investment expenditure does not rise much until the firm can accumulate a certain amount of cash flow. Without sufficient internal funds, the required return rate on externally raised funds still remains high, which limits the increased profitability of an investment. Essentially, this is because an investment needs a down payment as shown in section 2, due to the imperfect information that is given.

Further, let us compare the initial responses of investment and the capital price. The lower two panels in Figure 3 show that from periods 0 to 2, investment starts to boom gradually according to the increase in its net worth (or accumulated profit), while the capital price has already started to fall. Since capital price is the proxy of profitability, my simulation results suggest that profitability and investment can move in opposite directions. This finding is consistent with many empirical studies reporting the poor explanatory power of Tobin's  $Q$  in estimating investment functions, since naive  $Q$  theory predicts a one-to-one relationship between profitability and investment.<sup>20</sup> Among many empirical studies on firms' investment, a work by Lamont (2000) provides an insightful empirical finding regarding the relationship between actual investment and profitability. According to the paper, US data show weakly *negative contemporaneous* correlation between investment and current stock returns, mainly because of investment *lag*. Lamont (2000) presents empirical evidence that, while actual investment expenditure responds to stock returns with lags, their investment *plan* (based on survey data) reveals its *positive contemporaneous* correlation with stock returns. I cannot specify the reason behind this lagged actual investment. However, the empirical evidence presented by Lamont (2000) seems to support my simulation results.

Another interest is the dynamic behavior of corporate demand for liquidity. The lower two panels in Figure 4 present the impulse response of corporate liquidity demand and the degree of liquidity dependence. With the impact of a positive productivity shock, the capital price sharply rises, as similarly observed in Tobin's  $Q$  theory.

The higher capital price implies that the entrepreneur's investment is more profitable. This reduces the marginal benefit of holding liquidity, and thus the degree of liquidity dependence (liquidity demand divided by investment) falls. Firms tend to find more profitable investment projects in booms, and thus they do not need to rely on credit lines from a financial intermediary to withstand liquidity shocks. The lowest panel in Figure

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<sup>20</sup>Among such studies are Fazzari, Hubbard, and Petersen (1988) and Hoshi, Kashyap, and Sharfstein (1991).

4 reflects this lower marginal benefit for holding liquidity. On the other hand, liquidity demand (degree of liquidity dependence multiplied by investment volume) itself shows the net effect of the fall in the degree of liquidity dependence and increase in investment. Under my calibrated parameter settings, corporate liquidity demand stays almost still on impact, since these two opposite effects approximately cancel each other out. One quarter later, it starts to go up, since the latter effect, increase in investment, dominates the former effect.

### **3.2.2 *Impulse response to a wealth shock***

The wealth shock introduced here is a one-time transfer of a unit of wealth from entrepreneurs to consumers. This experiment is insightful in understanding the nature of agency cost models. Recall that in standard RBC models, where information is complete and thus corporate finance is a trivial matter for business cycles, a transfer of wealth from one agent to another does not cause any real change in the economy. In agency cost models, however, a transfer of wealth among different agents induces a non-trivial real effect on a firm's investment. This is because the quantity of internal funds of entrepreneurs (note that this is the firm's net worth in my model here) plays a significant role in agency cost models. Figures 6 and 7 show the result of this wealth shock simulation.

As can be seen in the figures, a one-time transfer of wealth from entrepreneurs to consumers causes a downturn of output, investment, and aggregate consumption in spite of the temporary increase in the household's consumption. Thus even if the aggregate net worth in the economy as a whole stays constant, a re-distribution of wealth from firms to households can cause a recession, if agency cost is a non-trivial issue. Similar results of this wealth re-distribution are observed in other agency cost models such as Carlstrom and Fuerst (1997) and Kiyotaki and Moore (1997).

### **3.2.3 *Sensitivity analysis***

The most controversial parameters here are the mean of the distribution of liquidity shocks in terms of investment volume and the entrepreneur's share of profit. As shown in the upper panel in Figure 8, the output dynamics are fairly robust for various means of liquidity shocks. (It seems as if there is only one line, but actually there are several lines overlaid.) Essentially, this is because whatever distribution is expected, the optimal cut-off level of liquidity shock is mainly determined by the entrepreneur's technology itself. In contrast, the profit share of the entrepreneur ( $= 1 - \omega_0/\omega_1$ ) dramatically

changes output dynamics. For instance, as mentioned in the previous subsection, with  $\omega_0/\omega_1 = 1$  (or  $B = 0$ , equivalently) the hump-shaped response of output and investment totally disappears. As can be seen in the lower panel of Figure 8, the hump-shaped dynamics require a certain magnitude of agency cost to be generated.

## 4 Discussion: relationships with the lending view studies

One of the major predictions of the “lending view” theory is that firms will be more bank loan-dependent in recessions. According to the lending view, this cyclical pattern of firms’ financing structure can be explained as follows. During recessions, investment projects are not so profitable on average as in booms; firms cut some projects whose returns do not exceed their financing costs. Since direct financing, such as equity finance, is usually more costly than loans from an intermediary, the result of cutting those unprofitable investment projects is to increase the ratio of bank loan financing in total financing. The mechanism that governs the cyclical fluctuations of financial structure in my model is slightly different from the standard lending view, but as I have already discussed in the previous subsection, both the lending view and my DGE model yield very similar predictions. The similarity is that in my model, firms become more liquidity dependent in recessions, because the lower profitability of their investment projects raises the marginal benefit of holding liquidity, while firms in the lending view demand more bank loan financing, because the marginal cost of obtaining it is lower. The difference is that the lending view considers *asset substitution* such as substitution of bank loans with equity financing. This is in contrast to my model, where the firm’s choice is whether to demand credit lines from banks or not. Let us see this point more precisely. Differentiating the first order condition (eqn(7)) in the financial contract to obtain,

$$\frac{\partial \bar{\omega}}{\partial q} = \frac{-\int_0^{\bar{\omega}} \Phi(\omega) d\omega}{q\Phi(\bar{\omega})} \leq 0 \quad (25)$$

which directly implies that the optimal credit line offered by the financial intermediary will decrease when investment projects become more profitable. This relation in eqn(25) is the source of the negative correlation between capital price (investment profitability) and the firm’s degree of liquidity dependence  $x$  in eqn(10) as discussed so far. This can

be verified by the following relation,

$$\begin{aligned}
\frac{\partial x}{\partial q} &= \frac{\partial \bar{\omega}}{\partial q} \frac{\partial x}{\partial \bar{\omega}} \\
&= \frac{\partial \bar{\omega}}{\partial q} \frac{\partial}{\partial \bar{\omega}} \left( \frac{\int_0^{\bar{\omega}} \omega \phi(\omega) d\omega}{\Phi(\bar{\omega}) \omega_1} \right) \\
&= \frac{\partial \bar{\omega}}{\partial q} \underbrace{\omega_1 \phi(\bar{\omega})}_{\leq 0} \underbrace{\int_0^{\bar{\omega}} (\bar{\omega} - \omega) \phi(\omega) d\omega}_{\geq 0} \frac{1}{(\Phi(\bar{\omega}) \omega_1)^2} \\
&\leq 0.
\end{aligned}$$

Basically, raising credit lines from the intermediary has a trade-off. A higher credit line is beneficial in withstanding larger liquidity shocks, while it reduces investment profitability and thus the volume of investment. When investment projects are highly profitable on average, both firms and consumers are willing to cut credit lines, since they have larger investment volumes. Because of this mechanism, I find that the degree of liquidity dependence tends to be counter-cyclical in the simulation results, which is consistent with the actual observed data as shown in Figures 1 and 2.

Another prediction of the lending view is that smaller firms, which are usually considered to be confronted with higher financing costs, are more bank loan-dependent. Another similarity can be derived from the variant of the HT model regarding this prediction. Eqn(7) implies that the credit line given to a firm does not depend on either  $\omega_0$  or  $\omega_1$ , but solely on  $q$ . Consequently, the optimal credit line in terms of the firm's NPV,  $\bar{\omega}/\omega_1$  (or in terms of pledgeable value,  $\bar{\omega}/\omega_0$ ) is higher for a firm with lower  $\omega_1$  (or  $\omega_0$ ). In other words, a firm with larger NPV tends to demand less liquidity than smaller firms in terms of their NPVs. This is a direct result of the insurance provided by the financial intermediary. In addition, a small firm's (maximum) liquidity demand,  $\bar{\omega}i$  divided by its NPV,  $\omega_1 i$  tends to be more sensitive to changes in profitability than a large firm's liquidity demand. That is,

$$\frac{d(\bar{\omega}/\omega_1^B)}{dq} > \frac{d(\bar{\omega}/\omega_1^A)}{dq}, \quad \text{for } \omega_1^A > \omega_1^B. \quad (26)$$

This relation is consistent with the common observation that smaller firms are more likely to suffer liquidity shortages during recessions (interpreted as periods when  $q$  is lower) than large firms.<sup>21</sup>

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<sup>21</sup>However, the general consequences of heterogeneity in firms' NPV are not examined in my DGE model. My DGE model allows heterogeneity only for levels of net worth.

## 5 Concluding remarks

Although the HT model is highly stylized, it requires a much less specific environment than might appear to be the case. Recall the calibration in section 3. I need to specify only two parameters and one distribution for entrepreneurial technology, namely  $\omega_1$ ,  $\omega_0$  and  $\Phi$ . Actually, as long as we are adhering to one-to-one transformation technology in capital production,  $\omega_1\Phi(\omega_1)$  must be set at one, and therefore only one parameter and one distribution need to be calibrated. This implies that the hump-shaped dynamics of output are robust for a broad class of models in which the investment process is characterized by *leakage* due to moral hazard or imperfect information. My guess is that any reasonable theory that yields an investment function similar to eqn(8) is consistent with hump-shaped dynamics of output. However, of course, this must await further research on this issue to be verified.

A weakness of my model is that it lacks the ability to analyze the role of public liquidity, since there is no aggregate uncertainty present in the economy. Intuitively, the role of the government is to eliminate the aggregate uncertainty to achieve at least the second-best outcome on the production side of the economy. Incorporating aggregate uncertainty and hence the role of government-supplied liquidity is potentially interesting for two reasons. One is that such a model could provide much richer insight into economic welfare. The other is that it would allow us to analyze the business cycle patterns of liquidity premiums for government-supplied securities, such as T-bills. These issues remain open for future research.

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