Essays in Macroeconomics and Corporate Finance

Ander Perez

London School of Economics and Political Science

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Declaration

I certify that the thesis I have presented for examination for the MPhil/PhD degree of the London School of Economics and Political Science is solely my own work other than where I have clearly indicated that it is the work of others (in which case the extent of any work carried out jointly by me and any other person is clearly identified in it). The copyright of this thesis rests with the author. Quotation from it is permitted, provided that full acknowledgement is made. This thesis may not be reproduced without the prior written consent of the author. I warrant that this authorization does not, to the best of my belief, infringe the rights of any third party.

I certify that chapter 3 of this thesis, "Financial Innovation, Macroeconomic Stability and Systemic Crises", was coauthored with Prasanna Gai, Sujit Kapadia and Stephen Millard. I, Ander Perez, contributed in excess of 50 percent to the genesis of the project and to the work on the model and the writing of the text.

Ander Perez

Abstract

This thesis consists of three essays at the intersection of macroeconomics and corporate finance. The broad theme that links the three chapters is the study of how endogenous borrowing constraints that affect firms and financial intermediaries influence aggregate investment.

In Chapter I, the existing theoretical framework studying how financial constraints in firms may make economies more sensitive to shocks (the 'financial accelerator') is extended to take account of firms' precautionary investment behaviour when they anticipate future liquidity constraints. This behaviour is at the source of a powerful amplification mechanism of shocks, and is also able to account for the documented dynamics of the composition of investment across the business cycle: in particular how risky, illiquid investment as a share of total investment fluctuates both at the firm and at the aggregate level.

Chapter II studies how the public supply of liquidity affects the private creation of liquidity by firms (inside liquidity), and how this interacts with firms' demand for liquidity to influence investment and capital accumulation. The conditions under which government debt may boost or reduce private investment are shown to depend on three channels: (1) a crowding-in effect, by enhancing aggregate liquidity, (2) a crowding-out effect, by reducing the collateral value of entrepreneurial assets and (3) a redistributive effect. The model also shows how a production economy with endogenous liquidity can help resolve some important asset pricing puzzles. Finally, the business cycle properties of the model are studied.

Chapter III shows how recent developments in financial markets may have made economies less vulnerable to banking crises as they widen access to liquidity, but by relaxing financial constraints facing financial intermediaries, they imply that, should a crisis occur, its impact could be more severe than previously. These effects may be reinforced by greater macroeconomic stability. Finally, financial intermediaries are shown to under-insure and over-borrow from a constrained-efficient viewpoint.

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Ander Perez

Contents

List of Figures

List of Tables

Chapter 1

Credit Constraints, Firms' Precautionary Investment, and the Business Cycle

1.1 Introduction

There is a large body of research on the role of financial frictions in amplifying business cycles and monetary policy shocks. Most of this work is focused on studying how firms' investment *capacity* is affected by tighter borrowing constraints in recessions or following a tightening of monetary policy, either directly through a balance sheet channel (Bernanke and Gertler (1989), Kiyotaki and Moore (1997), Bernanke, Gertler and Gilchrist (1999)) or indirectly through a decreased supply of intermediated finance (Holmstrom and Tirole (1997), Bolton and Freixas (2003), Van den Heuvel (2007)). In either case, all of these theories describe how firms are *constrained in the amount* they can invest following a shock.

There has been little focus in the literature however on an amplification and propagation mechanism that studies how changes in the likelihood of being credit constrained in the future may be affecting firms' *willingness* to invest and firms' *preference* for the *type* of investment they carry out. In short, firms that anticipate being credit constrained in the future may wish to retain more liquid balance sheets by investing less or investing differently.

Empirical evidence suggests indeed that firms' precautionary behaviour in anticipation of future expected financial constraints is a key determinant of their financial and investment decisions. Recent surveys by Graham and Harvey (2001) and Bancel and Mittoo (2002) find that CFOs consider financial flexibility (having enough internal funds to avoid having to fore-go positive Net Present Value projects in the future) to be the primary determinant of their policy decisions. Almeida, Campello and Weisbach (2004) report that the expectation of future financing problems significantly affects firms' investment policies, and Caggesse and Cunat (2007) find that it significantly affects hiring decisions.

The relevance of this approach is further enhanced by two observations. On the one hand, despite the fact that a small fraction of agents are observed to be financially constrained at any given point in time, a much larger fraction may anticipate the possibility of being constrained in the future. The importance of this distinction between the effect of the *anticipation* of constraints and the *contemporaneous* effect of constraints has already been pointed out in studies of the buffer stock behaviour of consumers. On the other hand, the subset of firms that suffer most from financial constraints and hence for which these considerations are relevant (small and privately-owned firms) is a very sizeable portion of economic activity, and in the US accounts for about one half of private-sector GDP and employment. [1]

As is suggested in the empirical evidence mentioned above, firms may insulate themselves from potential future credit rationing by adjusting their financial policies,

[1] Data from the U.S. Small Business Administration Report 2003 show that non-farm businesses with less than 500 employees account for about half of private-sector GDP, employ more than half of private-sector labour, and over 1992-2002 generated between 60-80% of net new jobs annually.

their hiring decisions, their cash holdings, or their investment strategies. This paper focuses on the effects on investment decisions.[2] A number of questions arise. Can a mechanism capturing this precautionary element in firms' behaviour have significant effects on aggregate investment and output dynamics? Can it account for the behaviour of the composition of real investment across the business cycle, which current models studying the macroeconomic implications of agency costs cannot account for? Are frictions preventing optimal risk and liquidity management by firms a powerful amplification mechanism of macroeconomic shocks?

These questions are dealt with by analyzing a dynamic stochastic general equilibrium model of a production economy subject to aggregate and idiosyncratic uncertainty. In the model, entrepreneurial firms in the investment good-producing sector have access to a highly profitable technology that is subject to liquidity risk. They also have access to safe but low-return alternative investment opportunity. Their wealth is limited, and they enter into state contingent contracts with financial intermediaries, which resemble a combination of standard loans and credit lines.[3] Entrepreneurs are subject to limited commitment and collateral constraints, and this will limit the extent to which financial intermediaries can spread the idiosyncratic risk faced by entrepreneurs.

In this paper I *first* describe theoretically the mechanism for the proposed *precautionary channel* of amplification of macroeconomic shocks. Entrepreneurs need to collateralize their borrowing using their fixed capital. If a negative aggregate productivity shock hits the economy, fire sales of capital will cause valuations to drop, and this decreases the pledgeability of entrepreneurial returns. Given the persistence of aggregate

[2]With regards to financial policies, I take the approach that firms have a limited ability to use their capital structure to gain financial flexibility due to financial constraints. For example, a large fraction of firms do not have the flexibility to switch between debt and equity, or the ability to issue commercial paper. In any case, in the model firms borrow using state contingent contracts subject to collateral constraints, and decide optimally the extent to which they want to hedge using that contract or by adjusting their investment decisions.

[3]Small and medium sized enterprises rely overwhelmingly on financial intermediaries rather than financial markets for their financing and risk management activities (Cantillo and Wright (2000), Faulkender (2003), Petersen and Rajan (1994)) and do so mostly using loan commitment facilities (Kashyap et al. (2002) document that 70% of bank lending to U.S. small firms is done on a loan commitment basis).

shocks, firms anticipate being less able to rely on asset liquidations or spot borrowing to deal with any possible future idiosyncratic liquidity shocks, and shift the composition of their investment towards less volatile and more liquid, but less profitable, activities. This amplifies the effect of the initial shock.

Secondly, I show in a calibrated model that this mechanism is quantitatively significant. Furthermore, I find that the amplification mechanism has two features which match observed business cycle regularities. On the one hand, it is highly asymmetric, delivering short and sharp recessions, and prolonged moderate boom periods. The extent to which the amplification mechanism is symmetric or not depends on how positive and negative technology shocks affect the trade-off between current and future marginal rates of return on different types of investment differently, and on the extent to which credit constraints are more likely in recessions. On the other, this channel requires relatively smaller negative technology shocks to generate recessions than it does positive shocks to generate booms. In the extreme, shocks to the volatility of the stochastic productivity process can generate downturns without any change to fundamental technology parameters.

The *third* main result is that this model is able to account for the business cycle patterns of aggregate and firm-level composition of investment. This is in line with evidence presented in a number of recent empirical papers. Aghion, et al. (2007) find using a firm-level data-set that while the share of R&D investment over total investment is countercyclical for firms that do not face credit constraints, it becomes pro-cyclical for credit constrained firms. Furthermore, this is only observed in downturns, when the share of R&D for these firms falls drastically. Almeida, Campello and Weisbach (2004) find on the other hand that financially constrained firms' cash flow sensitivity of cash increases significantly in recessions, while it is unchanged for unconstrained firms. Aghion, et al. (2005) give evidence using data on the aggregate composition of investment of a panel of countries that the share of structural (long-term) investment over total investment decreases following shocks that can be expected to make firms more likely to be credit constrained in the near future, and also document that this effect is stronger for less financially developed economies. They find, importantly, that the effect of financial development on the strength of the financial accelerator does not act through a mechanism that alters the amount of investment, but rather the composition, something which is at odds with the main prediction in existing macro models of credit frictions, in which the effects of the expectations of future potential financial constraints are ignored.

These observations are at odds with the existing models of macroeconomic implications of agency costs in which expectations of future constraints do not affect firms' current actions. In my model, however, a worsening of expected credit conditions causes the composition of investment to shift to safer but lower return technologies (contrary to the Schumpeterian idea of "cleansing" recessions). Also, composition shifts to activities with a higher degree of asset tangibility, and towards activities that use more liquid collateral and collateral whose value is less pro-cyclical. Absent alternative safer investment technologies, firms increase their investment in liquid, marketable securities and cash.

Relationship with the Literature

This paper is closely related to the strand of literature studying the macroeconomic implications of endogenous borrowing constraints for firms, such as Bernanke and Gertler (1989), Holmstrom and Tirole (1997), Kiyotaki and Moore (1997), Bernanke, Gertler and Gilchrist (1999), Bolton and Freixas (2003), Krishnamurthy (2003), Rampini (2004) and Van den Heuvel (2007). The majority of the papers in this literature does not study issues of risk-sharing and insurance, and instead focus mainly on how credit frictions affect the ability of firms to invest.[4] Krishnamurthy (2003) and Rampini (2004) are

[4]Stochastic models in this literature abstract from issues of risk management by making certain modelling choices that make risk irrelevant for entrepreneurs, such as assuming risk neutrality, linear production technologies, or permanently binding credit constraints.

an exception however. Krishnamurthy (2003) studies how introducing state-contingent claims eliminates the Kiyotaki and Moore (1997) mechanism, and shows that an aggregate constraint on the capacity of the economy to provide such insurance against aggregate shocks reinstates the mechanism, only that the constraint is on the side of the suppliers of finance. I extend that analysis along three key dimensions. Firstly, Krishnamurthy (2003) does not study the ex-ante effects of limited insurance capacity on the optimal investment choice of firms, which is the key element of the new mechanism I introduce in this paper. Secondly, I extend the model to a fully dynamic setup. Finally, I integrate the analysis in a fully general equilibrium model to be able to assess quantitatively the importance of this channel. A paper closely related in spirit is Rampini (2004), in which a model is introduced that delivers pro-cyclical entrepreneurial activity and amplification of technology shocks. The main difference with my paper is that his mechanism relies on entrepreneurs' risk aversion as the only motive for risk management, while in my setup demand for insurance is production-related.

There is another strand of literature that studies the macroeconomic impact of uninsurable idiosyncratic labour-income risk (Huggett (1993), Aiyagari (1994), Krusell and Smith (1998)) or uninsurable investment risk (Acemoglu and Zilibotti (1997), Angeletos and Calvet (2005, 2006), Covas (2006)) in the neoclassical growth model, to analyze issues related to capital accumulation, equilibrium real interest rates and output growth rates. They do not study however if and how market incompleteness varies across the cycle, and how this endogeneity of the risk-sharing opportunities affects cyclical fluctuations.

Regarding the corporate finance literature, a number of theoretical papers have identified the different sources of firms' insurance demand. One such motive is that if firms face costs of raising external finance, or indeed the prospect of being credit rationed, they may find it optimal to hedge against low cash-flow realizations to avoid having to fore-go positive NPV projects, a motive studied formally in Froot, Scharfstein and Stein

(1993). Another important source is the risk-aversion of entrepreneurs who, for incentive reasons, have most of their personal wealth invested in the venture they manage, and who also hold a controlling stake in that venture (Stulz (1984)).[5]

The remainder of the paper is organized as follows. Section 1.2 studies in detail the problem faced by entrepreneurial agents and financial intermediaries in a partial equilibrium set-up. Section 1.3 embeds this analysis in a fully general equilibrium dynamic stochastic model. The steady state of the model, and the calibration, are discussed in section 1.4. Section 1.5 presents the main results of the model. Section 1.6 presents empirical evidence. Finally, section 1.7 concludes.

1.2 Partial Equilibrium Analysis of Entrepreneurs and Financial Intermediaries

In this section I focus on the partial equilibrium analysis of entrepreneurs and financial intermediaries, and in the following section I embed this partial equilibrium setup in a general equilibrium framework. For clarity, I begin here by making a brief description of the whole economy in which the entrepreneurial and intermediary sectors will be embedded. An explanatory chart to aid in understanding the interrelationships in the model economy is in figure (1.1).

Consider an infinite horizon, discrete-time economy, populated by *four types of agents*: households (measure $1-\eta$), entrepreneurs (measure η), firms (measure 1) and banks (measure 1), where within each type there is a continuum of agents. There are *three types of goods*: consumption goods, investment goods, and entrepreneurial capital ("capital" from now on). Entrepreneurs produce the investment good using capital,

[5]Other motives have also been pointed out in the literature, such as hedging as a way to avoid non-linear costs of financial distress (Greenwald and Stiglitz (1993), Smith and Stulz (1985)), to resolve conflicts of interest between bond-holders and equity-holders, or between managers and providers of finance, and hedging to avoid tax non-linearities (Smith and Stulz (1985)).

and are subject to agency problems when seeking external finance. They are financed using their own net worth and external funds from households through financial intermediaries. Firms produce the consumption good using labour (from households and entrepreneurs) and the investment good, and are not subject to any agency problems. The model uses consumption goods as the numeraire.

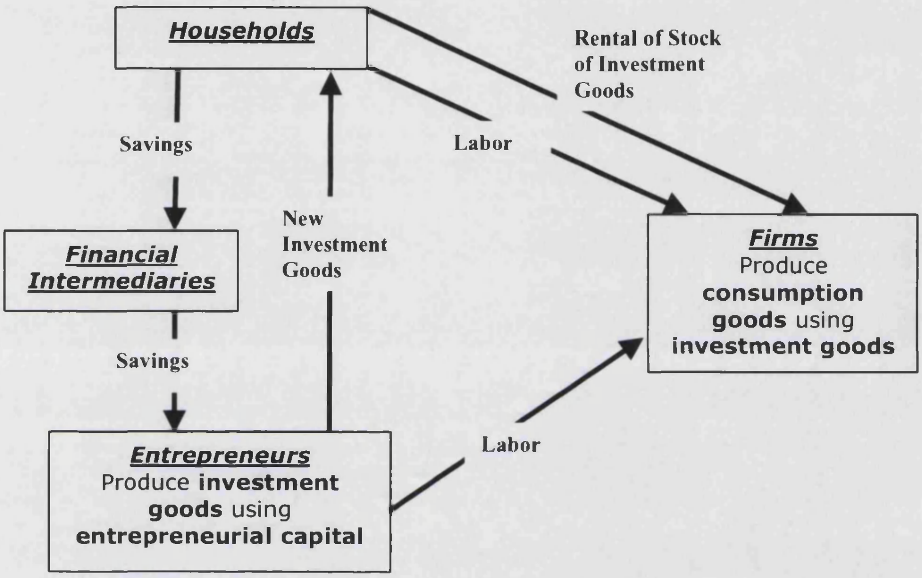

Figure 1.1: The Economy - Agents and their Economic Relationships

Now I turn to analyze the entrepreneurs' and intermediaries' problem in detail.

1.2.1 Entrepreneurs

There are overlapping-generations of two-period lived entrepreneurs, and within each generation there is a continuum of them. Entrepreneurs are risk-neutral and maximize expected utility of consumption in their final period.

An entrepreneur alive in period t (which could either be a newborn or a second-period entrepreneur) can invest in two different technologies, both of which produce capital (to be used by final consumption good producing firms) using consumption goods as the sole input. The difference between both technologies is that one produces safe returns, is less productive, and uses tangible (collateralizable) capital, while the other is more productive, risky and uses intangible capital. One could think of the first technology as expanding an existing production plant, while the second technology could be thought of as investment in marketing in order to start selling products in a new regional market or as R&D investment. Both production processes take place *within* the period, and hence are not subject to aggregate uncertainty, which is resolved at the beginning of the period.

In particular, the first technology produces a return $a_s i_{s,t}$ in terms of capital goods, where $a_s > 0$, to be sold at price q_t, and requires investing a total amount $1/2ci_{s,t}^2$. The second technology produces an expected return of $E(a_r)i_{r,t}$ capital goods plus $ei_{r,t}$ consumption goods, and requires investing a total amount $1/2di_{r,t}^2$. I assume that $E(a_r) > a_s$, and that a_r can take two values, $a_r^H > 0$ or zero with equal probability.

An entrepreneur born in period t will make a first investment choice at the beginning of t and a second one at the beginning of period $t + 1$. It is convenient to study the optimal investment problem backwards. In period $t + 1$ an entrepreneur with wealth n_{t+1} solves the following optimization problem:

$$\max_{i_{s,t+1}, i_{r,t+1}} q_{t+1}a_s i_{s,t+1} + [q_{t+1}E(a_r) + e]i_{r,t+1}, \tag{1.1}$$

$$s.t.$$

$$1/2ci_{s,t+1}^2 + 1/2di_{r,t+1}^2 = n_{t+1} + b_{t+1} \tag{1.2}$$

where $i_{s,t+1}$ is the investment in the safe technology, $i_{r,t+1}$ is the investment in the risky technology, n_{t+1} is the wealth with which an entrepreneur enters period $t+1$, and b_{t+1} is the position in safe bonds (borrowing if $b_{t+1} > 0$, lending if $b_{t+1} < 0$). Absent any borrowing constraints, optimal investment and borrowing positions are:

$$
\begin{aligned}
i_{s,t+1} &= \frac{q_{t+1}a_s}{c} & (1.3)\\
i_{r,t+1} &= \frac{[q_{t+1}E(a_r)+e]}{d} & (1.4)\\
b_{t+1} &= 1/2\frac{(q_{t+1}a_s)^2}{c} + 1/2\frac{[q_{t+1}E(a_r)+e]^2}{d} - n_{t+1}. & (1.5)
\end{aligned}
$$

One of our objects of interest is the study of the cyclical behaviour of risky, productive investment as a share of safe investment, which in this case is given by:

$$
\frac{i_{r,t+1}}{i_{s,t+1}} = \frac{[q_{t+1}E(a_r)+e]}{q_{t+1}a_s}\frac{c}{d}. \tag{1.6}
$$

This ratio turns out to be countercyclical, or, in other words, in a world without credit constraints the share of R&D and other risky activities increases in downturns. In good times, short run returns are high (q is high, which is the only element driving the immediate returns), and relatively more so than long-run returns given that the mean-reverting process driving q_t is dampened by the constant term e, making returns to the risky activity fluctuate less across the business cycle.

Consumption by entrepreneurs in their second period in the unconstrained case is:

$$
\begin{aligned}
c^i_{t+1} &= \frac{(q_{t+1}a_s)^2}{c} + \left(q_{t+1}a^i_r + e\right)\frac{[q_{t+1}E(a_r)+e]}{d} \\
&\quad - (1+r_{t+1})\left(1/2\frac{(q_{t+1}a_s)^2}{c} + 1/2\frac{[q_{t+1}E(a_r)+e]^2}{d} - n_{t+1}\right)
\end{aligned} \tag{1.7}
$$

In expression (1.7), superscript i indicates the outcome of the risky project. Note in this expression that consumption is linear in beginning-of-period net worth.

When we consider credit frictions this result may no longer hold. In particular, assume that an entrepreneur is prevented from borrowing more a multiple μ of its short run profits in the safe activity. This captures the extent to which the entrepreneur can borrow using the returns to the short run activity as collateral. Credit constraints will bind as long as first best borrowing is above the pledgeable amount, or:

$$1/2\frac{(q_{t+1}a_s)^2}{c} + 1/2\frac{[q_{t+1}E(a_r) + e]^2}{d} - n_{t+1} > \mu\frac{(q_{t+1}a_s)^2}{c}$$

This is more likely to happen when q is low, ie. in downturns. Intuitively, the combination of low short run profits *and* a shift of the opportunity cost trade-off towards the long-run risky activity being *relatively* more attractive than the short run activity in recessions than in booms means that borrowing constraints are more likely to bind in negative aggregate states. This means that the long-run risky activity may be less countercyclical than in the unconstrained scenario, or indeed procyclical. With binding borrowing constraints in period $t + 1$, optimal investment and borrowing positions in that period are:

$$i_{s,t+1} = \frac{q_{t+1}a_s}{c}\frac{(1 - \mu(1 + r_{t+1} - \lambda_{t+1}))}{\lambda_{t+1}} \tag{1.8}$$

$$i_{r,t+1} = \frac{[q_{t+1}E(a_r) + e]}{\lambda_{t+1}d} \tag{1.9}$$

$$b_{t+1} = \mu q_{t+1}a_s i_{s,t+1}. \tag{1.10}$$

Combining expressions (1.2), (1.8) and (1.9), we get a consumption function in the constrained case which is a nonlinear (concave) function of beginning-of-period net worth. Now let's focus on the *first period's* decision. The problem solved by an entrepreneur at the beginning of his lifetime is:

$$\max_{i_{s,t},i_{r,t},b_t} E_t(c_{t+1}(n_{t+1}))$$

$$s.t.$$

$$
\begin{aligned}
1/2ci_{s,t}^2 + 1/2di_{r,t}^2 &= w_t + b_t \\
b_t &\leq \mu q_t a_s i_{s,t} \\
n_{t+1}^i &= q_t a_s i_{s,t} + \left(q_t a_r^i + e\right) i_{r,t} - (1 + r_t) b_t
\end{aligned}
$$

The potential for binding constraints in some states introduces an important nonlinearity in the relationship between the net worth entrepreneurs transfer into their second period and returns from investment in that period. This nonlinearity introduces a motive for smoothing this net worth, and to the extent that financial frictions may limit the ability to share entrepreneurial risk, this hedging incentive may affect first-period investment decisions. This is the essence of the *precautionary investment motive* described in the introduction.

1.2.2 Financial Intermediaries

Financial intermediaries in this model channel savings received from households and lend to entrepreneurs. At the beginning of every period, all of the households' savings are deposited in financial intermediaries, which commit to purchase investment goods from entrepreneurs and return it to households by the end of the period. Financial intermediaries use that liquidity to provide loans to entrepreneurs.

1.3 General Equilibrium

In this section, I embed the entrepreneurial and financial intermediation sectors in a general equilibrium framework. I will start by explaining the choices faced by households and firms, and then discuss how the entrepreneurial sector and the financial intermediaries are introduced into the general equilibrium framework. In order to understand the sequence of events in this economy, Table (1.1) summarizes what happens within each period.

Table 1.1: Sequence of Events within One Period

1	θ_t, the aggregate productivity shock, is realized.
2	Firms hire labor from households and entrepreneurs and rent capital from households. These inputs are used to produce the consumption good, $Y_t = \theta_t F(K_t, H_t, H_t^e)$.
3	Households make their consumption and savings choice. All savings are deposited in financial intermediaries, which commit to purchase capital from entrepreneurs and return it to households by the end of the period.
4	Financial Intermediaries use the resources obtained from households to provide loans to entrepreneurs.
5	Entrepreneurs borrow resources from the Intermediaries. Entrepreneurs decide how to allocate their investment into risky and safe projects.
6	The idiosyncratic entrepreneurial technology shock is realized. Loans are repaid to the Intermediaries.
7	Intermediaries purchase all of the investment goods from entrepreneurs, and hands them to households. Banks end the period with no liquidity. Old entrepreneurs consume and die.

In what follows, all variables in upper case indicate aggregate quantities.

1.3.1 Households

There is a continuum of risk-averse households, who maximize expected lifetime utility of consumption, c_t, and leisure, $(1 - L_t)$, taking as given wages w_t, the price of investment goods q_t, and the equilibrium rate of return on the investment goods r_{t+1}:

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t, 1 - L_t). \tag{1.11}$$

At the beginning of every period households choose their labour supply, and their optimal labour-leisure choice is given by:

$$\frac{u_L(t)}{u_c(t)} = w_t \tag{1.12}$$

They then choose their optimal consumption. All savings are deposited in financial intermediaries, which commit to purchase investment goods from entrepreneurs and return them to households by the end of the period. These investment goods are then rented to firms, which use it for production the following period and pay in return an interest rate of $1+r_{t+1}$ (which is stochastic and depends on the realization of θ_{t+1}). The optimal savings and consumption choice is given by:

$$u_c(t) = \beta E_t \left[u_c(t+1) \frac{q_{t+1}(1-\delta) + (1+r_{t+1})}{q_t} \right] \tag{1.13}$$

where $u_c(t)$ is the marginal utility of consumption in period t.

1.3.2 Firms

Firms produce the consumption good using a constant returns to scale production function:

$$Y_t = \theta_t F(K_t, H_t, H_t^e) \tag{1.14}$$

where K_t is the stock of investment goods, H_t is aggregate labour supplied by households, and $H_t^e = H^e$ is labour supplied by entrepreneurial agents (which is constant).

Perfect competition in the factor markets implies the following factor prices:

$$r_t = \theta_t F_1(t) - 1 \tag{1.15}$$

$$w_t = \theta_t F_2(t) \tag{1.16}$$

$$w_t^e = \theta_t F_3(t) \tag{1.17}$$

1.3.3 Market Clearing Conditions

There are four markets that need to clear in this economy: the markets for investment goods, consumption goods, entrepreneurial labour, and household labour. With regards to the last two, the labour supplied by households is equal to $H_t = (1-\eta)L_t$

on one hand, while on the other entrepreneurs supply labour inelastically and in the aggregate provide $H_t^e = \eta$.

The aggregate resource constraint (goods market equilibrium) in terms of expenditures is given by:

$$Y_t = (1-\eta)C_t + \eta C_t^e + \eta \sum_{i=Y,L,U} \pi^i I_{s,t}^i + \eta \sum_{i=Y,L,U} \pi^i I_{r,t}^i + \eta N_t \tag{1.18}$$

The first two terms in (1.18) capture aggregate consumption in this economy, by both households (C_t) and entrepreneurs (C_t^e). The third and fourth terms capture investment in the safe and risky technologies respectively by the three groups of entrepreneurs (young, old lucky and old unlucky), while the fifth term deals with aggregate savings of young entrepreneurs.[6]

The market for investment goods used by consumption goods producing firms clears at the price of q_t, according to the expression:

$$K_{t+1}(q_t) = (1-\delta)K_t + \frac{Y_t^e(q_t)}{q_t},$$

where Y_t^e is entrepreneurial production of new capital, and is given by:

$$Y_t^e(q_t) = \eta a_s \sum_{i=Y,L,U} \pi^i I_{s,t}^i(q_t) + \eta \frac{a_r}{2} \sum_{i=Y,L,U} \pi^i I_{r,t}^i(q_t) \tag{1.19}$$

1.3.4 Recursive Equilibrium Conditions

The recursive competitive equilibrium is defined by decision rules for K_{t+1}, C_t, H_t, $\{I_{s,t}^i\}_{i=Y,L,U}$, $\{I_{r,t}^i\}_{i=Y,L,U}$, N_{t+1}^L, N_{t+1}^U, B_t^Y, B_t^L, B_t^U, q_t and r_t, as a function of K_t, θ_t, and $\{N_t^i\}_{i=L,U}$. The appendix provides a detailed explanation of these recursive equi-

[6]Households can only transfer resources from one period to the next by purchasing capital (even if they could use a safe storage technology with no return they would not use it as it would be rate-of-return dominated by investment in k_{t+1}). Entrepreneurs on the other hand can only transfer any resources they have at the end of the period through a safe (zero-return) storage technology.

librium conditions, and of the computational procedure used to solve this model.

1.4 Calibration and Analysis of Steady State

1.4.1 Calibration

The model is parameterized at the non-stochastic steady state using values to replicate long-run empirical regularities in U.S. post-World War II macro data. In addition the calibration is designed so the results are comparable with the existing quantitative studies on agency costs and business cycle fluctuations, such as Carlstrom and Fuerst (1997).

The final good production technology is assumed to be Cobb-Douglas of the form

$$Y_t = \theta_t K_t^{\alpha^K} H_t^{\alpha} H_t^{\alpha^e}$$

with a capital share (α^K) of 0.36, a household labour share (α) of 0.63, and an entrepreneurial labour share (α^e) of 0.01. The share of entrepreneurial labour is positive to ensure that young entrepreneurs have positive net worth with probability one. It is chosen to be small so that the model dynamics closely resemble the standard RBC dynamics when the financial frictions in the model are removed. The capital depreciation rate is set to $\delta = 0.02$.

The technology shock, θ_t, follows the process

$$\log \theta_{t+1} = \rho \log \theta_t + \sigma_\varepsilon \varepsilon_{t+1}$$

where $\sigma = .01$ and $\rho = 0.95$, and $\varepsilon_{t+1} \sim N(0,1)$.

The utility function for households is of the form

$$U = \frac{c^{1-\gamma} - 1}{1-\gamma} + v(1-L)$$

with v chosen so that the steady-state level of hours is equal to 0.3. The intertemporal preference rate is set at $\beta = 0.99$, and the risk aversion parameter γ is set at 1, but higher values (up to 4) are also tested for robustness.

With regards to the calibration of the entrepreneurial sector parameters, we start by calibrating the pledgeability of entrepreneurial capital (captured by μ) to match empirically documented Loan-to-Value (LTV) ratios for commercial mortgage lending to small and medium-sized enterprises. Titman, Tompaidis, and Tsyplakov (2005) find that the LTV ratios (measured as the loan amount divided by the appraised value of the property) have values between 60% and 80% for over 75% of the loans the study, and an average of 65%.[7] In numerical simulations, the choice of this parameter is shown to be quite important for my results. For that reason I use a conservative choice in my baseline calibration of 70%. The two remaining parameters relate to the entrepreneurial risky technology (the multiplicative productivity factor, and the parameter regulating its curvature and hence the intensity of the demand for risk and liquidity management), and they are calibrated to match two empirical regularities: (1) the risk premium, and (2) the share of loans that are issued on a commitment basis. Regarding the latter, I use the value document by Kashyap et al. (2002), who find that 70% of bank lending by U.S. small firms is through credit lines. Regarding the former, I follow Carlstrom and Fuerst (1997) and use the average spread between the 3-month commercial paper rate and the prime rate (which for the period from April 1971 to June 1996 equals 187 basis points).

[7] They use data on 26,000 individual commercial mortgages originated in the U.S. between 1992 and 2002.

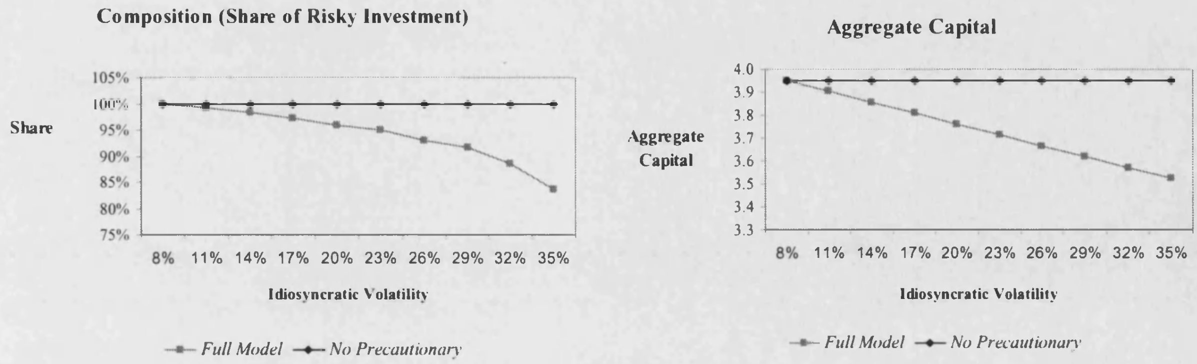

Figure 1.2: Composition of entrepreneurial investment and aggregate capital in the steady state, as a function of changes in idiosyncratic volatility.

1.4.2 Analysis of the Steady State

The analysis of the steady state of this model yields some interesting results. The steady state is obtained by eliminating the volatility of the aggregate productivity parameter, but preserving the idiosyncratic uncertainty element.

I then conduct an analysis by which I perform a mean-preserving increase in the idiosyncratic volatility parameter. The results are that the steady state composition of entrepreneurial investment shifts to a safer profile with higher volatility, and that the aggregate stock of investment goods in the economy is substantially lower, as is clear from figure (1.2). This is in contrast to standard models of credit frictions in which the anticipation of *future* financing problems do not affect *current* investment decisions. Those models predict that the share of risky productive investment is not sensitive to idiosyncratic volatility, and I reproduce that result in this model by removing the source of precautionary behaviour in firms, as is shown as well in figure (1.2) in the series labeled "*No Precautionary*".[8]

[8] The transformation of the model into one in which there is no precautionary behavior is straightforward and is done by altering the functional form of the second period entrepreneurial production opportunity to one with constant returns to scale in the only factor, entrepreneurial capital (as opposed to the benchmark setup with decreasing returns to scale in that same factor). This implies that the entrepreneur is no longer concerned with smoothing his net worth at the beginning of the second period and hence has no demand for insurance.

1.5 The Precautionary Channel of Amplification

I analyze the dynamics of this model by studying the behaviour of different aggregates in response to changes in aggregate productivity, or total factor productivity (TFP). I compare the response of the relevant aggregate variables in three models: a completely standard real business cycle (RBC) framework, a model with borrowing constraints but no precautionary channel, and the full model introduced in the previous section. The purpose of this section is to clarify how the amplification mechanism described in the previous sections works and in particular to highlight what the contribution of this mechanism is with respect to the standard financial accelerator.

I focus the attention on some aggregate quantities and prices that relate to entrepreneurial investment; in particular I will study the dynamic behaviour of the composition of entrepreneurs' investment between safe and risky investment, the price q_t of the investment goods produced by entrepreneurs and bought by firms, aggregate investment by consumption good-producing firms, and finally aggregate output. The results are in figure (1.3).

First, the dynamics of the standard RBC model are well known. I obtain these dynamics by eliminating the capital-producing sector (entrepreneurs) and assuming an infinitely elastic supply of capital at the price of unity. The response of investment and output mimics closely the evolution of the underlying technology process. In essence, there is little propagation in this version. The price of capital q_t does not react to changes in technology because of the assumption of infinite elasticity, and there are no compositional effects of investment changes.

Secondly, the dynamics of the standard financial accelerator can be obtained in the current framework through several ways. One is by *not* giving firms an investment choice and assuming that they are permanently credit constrained: firms will simply invest as much as possible in the risky activity every period. Another is by linearizing

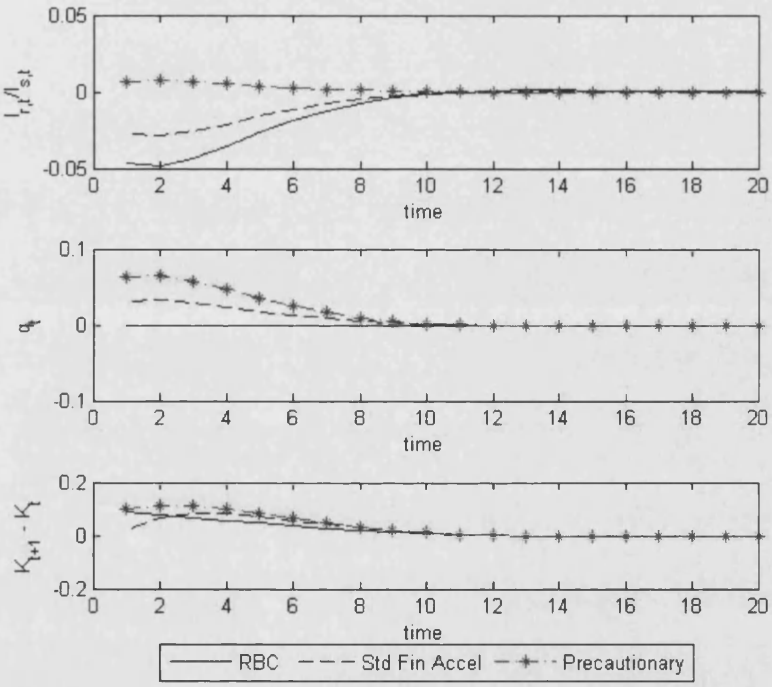

Figure 1.3: Impulse Response to a Positive One Standard Deviation Shock to Productivity (Periods = quarters).

the second period production function: this way, firms have no incentive to smooth second-period investment, and simply maximize first period investment in the risky activity and do not invest in the safe asset. I adopt the latter approach, without loss of generality. In either case, there is no compositional effect and no precautionary behaviour: even if firms anticipate rationally that the severity of credit constraints may increase the following period, this does not affect their current behaviour. This is the essence of the contribution of the precautionary mechanism introduced in this paper. The idea is not that firms behave in an irrational way by not reacting to the anticipation of future credit constraints, but that either the are *unable* to react (because they have no discretion as to how to invest or save, or because they always operate in a corner solution because they are assumed to be permanently credit constrained, etc...) or that they are *unwilling* to react (they have no motive to smooth end-of-period wealth, which implies they are risk neutral and that returns to investment the following period are linear in beginning-of-period net worth).

The cyclical dynamics in the standard financial accelerator are well known as well. Financial imperfections may amplify and add persistence to the effects of technology shocks, as is the case in figure (1.3), but do not affect the composition of investment. Two comments are in order. First, it is worthwhile noting that there is some controversy in the literature as to the extent to which financial imperfections dampen or amplify cycles, and different papers analyze scenarios in which one or the other result obtains. The focus of the results in this paper are on how taking into account firms' precautionary behaviour changes the way we should understand the way financial frictions affect aggregate investment dynamics, and in that respect contributes to that discussion. Secondly, there is less controversy in the literature surrounding the persistence effects of financial frictions, at least in terms of the qualitative effects. In the results in this paper the persistence effects are dampened with respect to frameworks in which entrepreneurs are modelled as infinitely lived and hence their net worth (the aggregate level and its distribution) becomes an important state variable that adds substantial persistence. In my model, entrepreneurs live for two periods, and hence the effect of net worth dynamics is significantly smaller. In any event, in the context of my framework it affects both the standard financial accelerator version and the precautionary channel version in the same way, and thus does not affect the comparison of both, which is the object of study.

Finally, if we observe the changes that occur in the aggregate dynamics as a result of considering firms' precautionary behaviour, we can notice that they are significant. The main idea of the precautionary channel is that if *future expected borrowing* conditions worsen, then entrepreneurs will adjust the riskiness of their investment portfolio by reducing their exposure to the risky technology. When a negative shock hits, firms understand that the shock will be persistent and that it means that the probability of being financially constrained next period increases. They react by decreasing their share of risky investment. This works both ways, so when a positive shock hits the economy and future expected borrowing conditions improve, entrepreneurs increase the riskiness of their investment portfolio. The precautionary model implies a larger contemporaneous response to shocks (more amplification), and smaller persistence. The intuition for this result is that firms anticipate future financial restrictions and react immediately. In the standard financial accelerator framework, in papers such as Carlstrom and Fuerst (1997) and Bernanke, Gertler and Gilchrist (2000), firms invest as much as they can at every point in time. This adds persistence to their effects; a negative shock may imply that entrepreneurs' net worth decreases slowly to reach its minimum several periods later, with entrepreneurial investment following that pattern. Taking into account a precautionary behaviour and the flexibility to adjust the investment portfolio means forward-looking firms may choose to react in advance to that to minimize future credit rationing.

Another important result is the asymmetry of effects, which can be seen in figure (1.4). Hansen and Prescott (2002) and Sichel (1993) find evidence that positive shocks

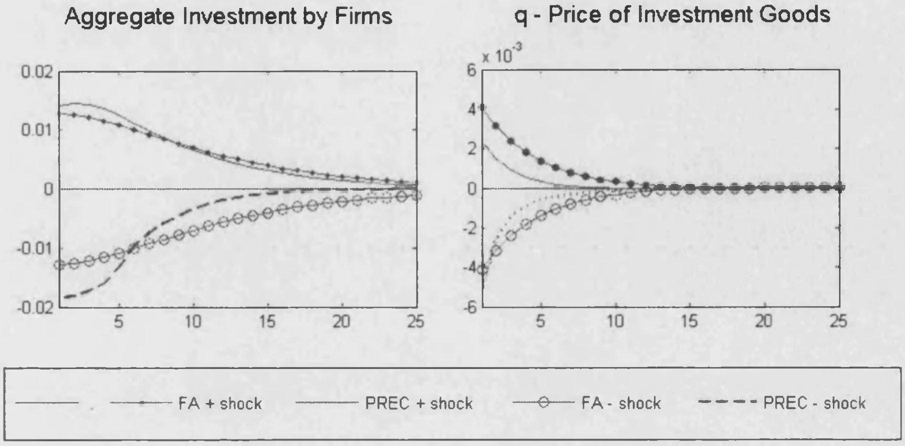

Figure 1.4: Asymmetry of Effects: Impulse Response Functions to a Positive and a Negative One Standard Deviation Shock to Productivity (Periods = quarters). (FA = Financial Accelerator Model; PREC = Precautionary Model)

produce smaller positive output effects than negative shocks produce negative output effects. The existing theory tries to explain this on the basis of capacity constraint models (Hansen and Prescott (2002), Danziger (2003)) and sticky price models (Devereux and Siu (2003)). In my framework, the key element to these results is in the nonlinear dynamics of the endogenous borrowing constraints. The ratio of risky to safe investment $I_{r,t}/I_{s,t}$ is procyclical in an unconstrained scenario, which implies that when credit constraints are taken into account, and bearing in mind that I_s is collateralizable and I_r is not, these will tend to bind more in downturns. The intuition is that in downturns several factors concur: profits are low, collateral values (q_t) are also low, and collateralizable assets become relatively more expensive (or rather, relatively less profitable, as the relative profitability gap between the risky technology and the safe one increases in downturns[9]). These three factors combine to make borrowing constraints countercyclical, and hence to make the effects of this mechanism strongly asymmetric. This

[9]This is clear by observing the ratio of the risky, productive investment as a share of safe investment

asymmetry in the pricing behaviour generates asymmetry in both the model with and the model without the precautionary element, but more so in the latter, the reason being that an asset price feedback effect kicks in in the precautionary model: firms do not internalize the future pricing effects of their current actions.

1.6 Empirical Evidence

In this section I present evidence that provides support to the predictions of the model analyzed in the previous sections. The predictions refer broadly to ex-ante reactions by entrepreneurial firms when the expectations about future risk-sharing conditions vary. These reactions may manifest themselves in particular decisions with respect to the choice of production technology along the dimensions of riskiness, length or collateralizability of the capital used, the choice of the share of cash and liquid securities as a share of total assets, and the choice of the level of investment.

Special care has to be taken to distinguish the effects of the specific channel identified in this paper, with the effects of the traditional credit channel. In particular, some of the empirical studies carried out to test the standard credit channel could be picking up the effects of the insurance channel identified in this paper. If firms' investment sensitivity to monetary policy shocks or productivity shocks is higher for small firms with a high degree of agency problems, this could be due to either a lack of ability to borrow to invest (a *corner solution*), or a lack of willingness to carry out such investments as an optimal decision that weighs in the prospect of being credit constrained in the fu-

in the unconstrained scenario, given by:

$$\frac{i_{r,t+1}}{i_{s,t+1}} = \frac{[q_{t+1}E(a_r) + e]}{q_{t+1}a_s}\frac{c}{d}.$$

In good times, short run returns are high (q is high, which is the only element driving the immediate returns), and relatively more so than long-run returns given that the mean-reverting process driving q_t is dampened by the constant term e, making returns to the risky activity fluctuate less across the business cycle.

ture and not being able to undertake profitable investment opportunities that may arise (an *interior solution*). If banks' loan supply is sensitive to monetary policy shocks or productivity shocks, and small firms with high agency problems are especially bank-dependent, then their investment reaction may be due to an inability to borrow today, or to the expectation that the current credit crunch will persist in time and may result in an inability to borrow in the future to withstand liquidity shocks or undertake investment opportunities. The empirical tests carried out in this section take this observational equivalence into account.

The broad prediction tested is that if risk-sharing conditions worsen in the present, or are expected to worsen in the future, then the asset composition strategies of high agency cost firms should reflect this in a particular way. We need to operationalize both elements of the prediction, the exogenous explicative component, and the endogenous reaction. We do so in a number of ways below, and we divide the analysis into two subsections, one analysing a firm-level panel data set of European firms, and another using aggregate U.S. investment data.

1.6.1 U.S. Aggregate Investment Data, the Business Cycle and Credit Conditions

In order to distinguish between different types of investment along the riskiness dimension, one strategy is to study the behaviour of Research & Development investment as a fraction of total investment. Another strategy is to study the behaviour of long-term, structural investment, again as a share of total investment. The U.S. is particularly convenient to study these aspects of investment as there is abundant data on industrial R&D activity, provided by the National Science Foundation.

R&D Investment Behaviour Across the Business Cycle

A component of investment which is likely to be very sensitive to liquidity insurance supply conditions is Research & Development spending. Some authors in the literature have pointed out the potential effect of business cycle fluctuations on research and development investment. Geroski and Walters (1995), Fatas (2000) and Barlevy (2004) all find evidence of a positive relationship between output and R&D.[10] Other studies have looked further into the topic by analysing the composition of R&D spending, and how that varies across the cycle. Rafferty (2003a and 2003b) documents that basic research increases in downturns, while development is procyclical. He also analyses in that work if cash flow constraints have a role in the variations of total R&D spending, and finds that they do, which suggests that availability of means to insure against negative liquidity shocks to those R&D projects should encourage investment in them. Interestingly, Hall (1992) finds that most R&D is financed by internal funds, which makes this type of investment especially reliant on being able to implement an optimal risk management strategy that does not leave a firm willing to engage in R&D development at some future stage totally dependent on external funds for that venture.[11]

I show in figure (1.5) some evidence for the cyclical pattern of R&D spending using data from the National Science Foundation for the United States from 1953 to 2005. I plot the share of R&D investment as a share of total fixed capital formation and compare the evolution of this ratio against NBER dated recessions in the United States. Again, this chart shows evidence of sharp contractions in the share of R&D spending at the onset of recessions and fast recoveries following the beginning of the upward section of the cycle.

I have conducted some further analysis studying variations in the share of R&D

[10]Geroski and Walters (1995) measure R&D spending by the number of patent applications, while Fatas (2000) and Barlevy (2004) look at R&D expenditures as reported by companies in the United States.

[11]More evidence in this line is provided by Himmelberg and Petersen (1994), who document that R&D spending at the firm level is very sensitive to cash flow.

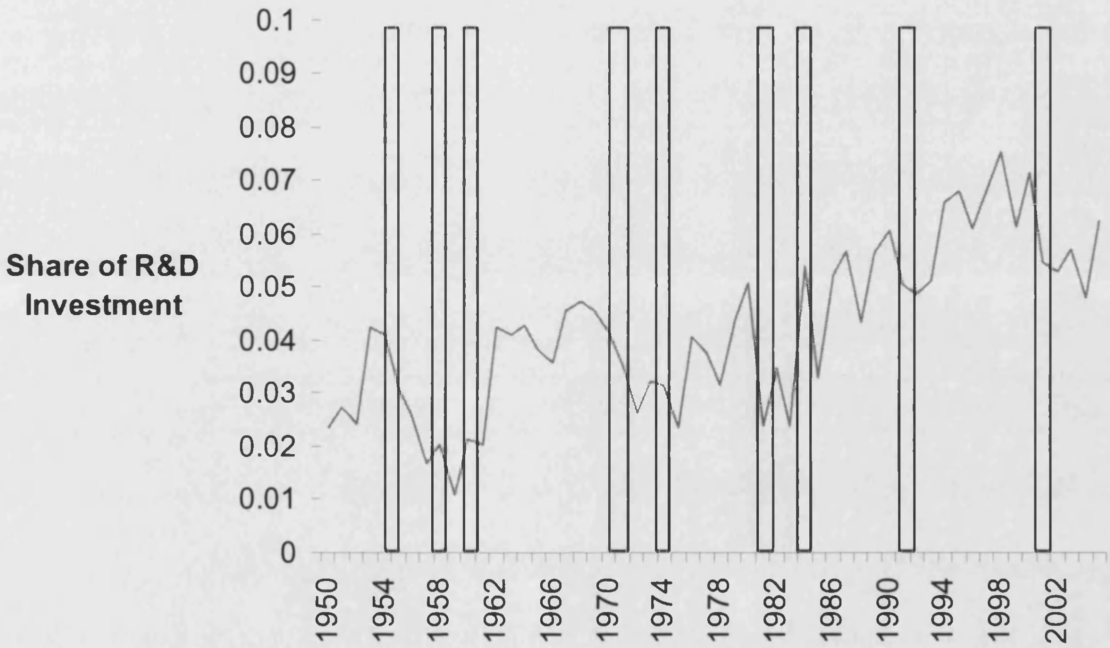

Figure 1.5: R&D Investment as a Share of Total Fixed Capital Formation (Data for investment for the U.S. from National Science Foundation)

investment exploiting certain differences at the sectorial level. The main premise is that certain types of firms should show a higher sensitivity in their ratios of R&D investment as a fraction of total investment than others. In particular, the model suggests that smaller firms (a proxy for higher agency costs), firms in more volatile sectors, and firms in sectors with a higher external finance dependence, should show a higher sensitivity.

Some tentative evidence, without resorting to formal econometric analysis, for all these three is shown below. One of the analyses looks at sectorial variation in investment across the cycle, where sectors are classified according to their volatility using a number of different criteria.[12] My criterion to classify industries as per their volatility uses a combination of measures such as the standard deviation of real wages, of input prices, of output prices, and the average horizon of investment projects within sectors. The data is divided into very low volatility sectors and very high volatility sectors (ignoring moderate sectors), and shown in figure (1.6) below. The data suggests that R&D spending is more sensitive in highly volatile sectors, as a share of total investment, in line with my predictions.

Another interesting measure is that of external dependence, where the precise definitions and classification are taken from Rajan and Zingales (1998). Again the data is divided into very low dependence sectors and very high dependence sectors (ignoring moderate sectors), and shown in figure (1.7) below. The data suggests that R&D spending sensitivity is not significantly different in both groups of firms. This lack of evidence may be due to either a lack of the effect posited, or indeed a failure in the specific index used, and I am currently investigating this more deeply.

Finally, I use average firm size within each sector to again divide the data into very low average size sectors and very high average size sectors (ignoring moderate sectors), and the results are shown in figure (1.8) below. The data suggests that R&D spending is more pro-cyclical in sectors with smaller sized firms, in line with my predictions.

[12]This measure is in line with that used by Huizinga (1992), and I compare my classification with the one in that paper for robustness.

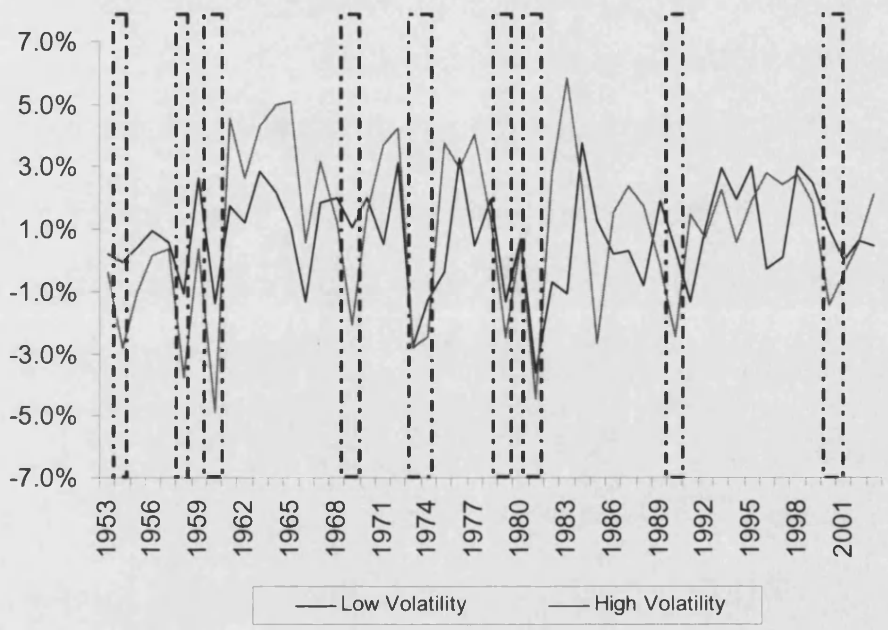

Figure 1.6: Annual % Variation in R&D Private Spending as a Share of Total Investment - Industries Classified by Volatility (using criterion that weighs input and output price volatility, uncertainty in outcome of investment projects, average duration of projects, etc...)

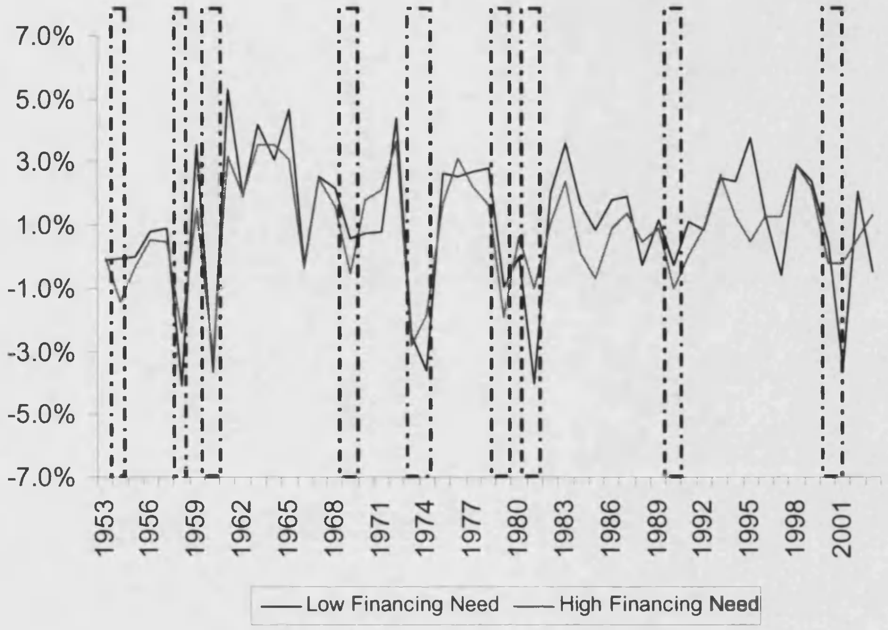

Figure 1.7: Annual % Variation in R&D Private Spending as a Share of Total Investment - Industries Classified as per the Rajan and Zingales (1998) index of External Dependence

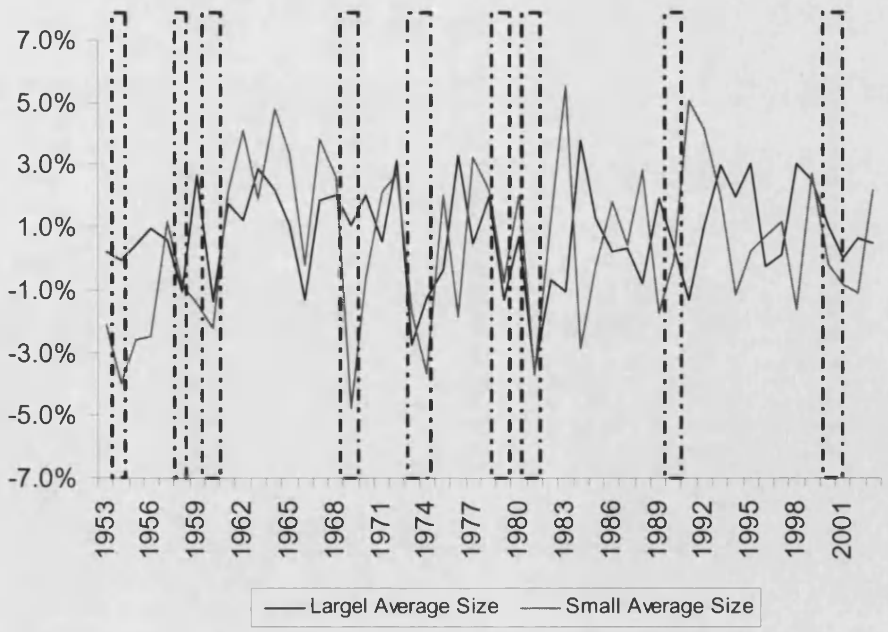

Figure 1.8: % Variations in ratio of R&D expenditures as a share of total investment

Long-Term Structural Investment and Credit Standards

One broad classification of investment with relevance for the topic of uncertainty is along the dimension of duration of the project. Longer projects, which carry a higher risk of facing intermediate episodes of reinvestment requirements, and a higher risk about returns inherent in that the conditions about demand and other aspects so far into the future will be more uncertain, will not be undertaken in case the risk-sharing opportunities are low. I construct a measure of the share of long-term investment as a proportion of total investment, using data from the OECD, and study how it varies across the cycle. The raw numbers for the United States are plotted in figure (1.9), which captures the evolution of this ratio over the past 50 years. Also plotted are the NBER dated recessions that have taken place during this period of time. The chart shows a clear cyclical pattern that is common to most of the recession episodes that occurred: the share of long-term investment falls significantly during downturns, and recovers with some lag as the boom begins.

With regards to the first element in the insurance channel, the worsening of expected insurance conditions, available U.S. data provides the opportunity to measure varying Bank credit conditions through the Senior Loan Officer Opinion Survey on Bank Lending Practices. This is a survey of approximately sixty large domestic banks and twenty-four U.S. branches and agencies of foreign banks conducted by the Federal Reserve. It is conducted quarterly, and questions cover changes in the standards and terms of the banks' lending and the state of business and household demand for loans.

The premise is that if credit conditions worsen (standards for credit lines increase,...) or are expected to worsen (bank liquidity expected to fall, collateralizable asset values expected to fall,...), high agency cost firms, and firms in industries with (a) riskier profiles and (b) higher financing needs, should be hit worst, and hence should see a higher reaction of their long-term structural investment ratio (as a fraction of total investment). As preliminary evidence, I show below, in chart (1.10), the reaction of the share of

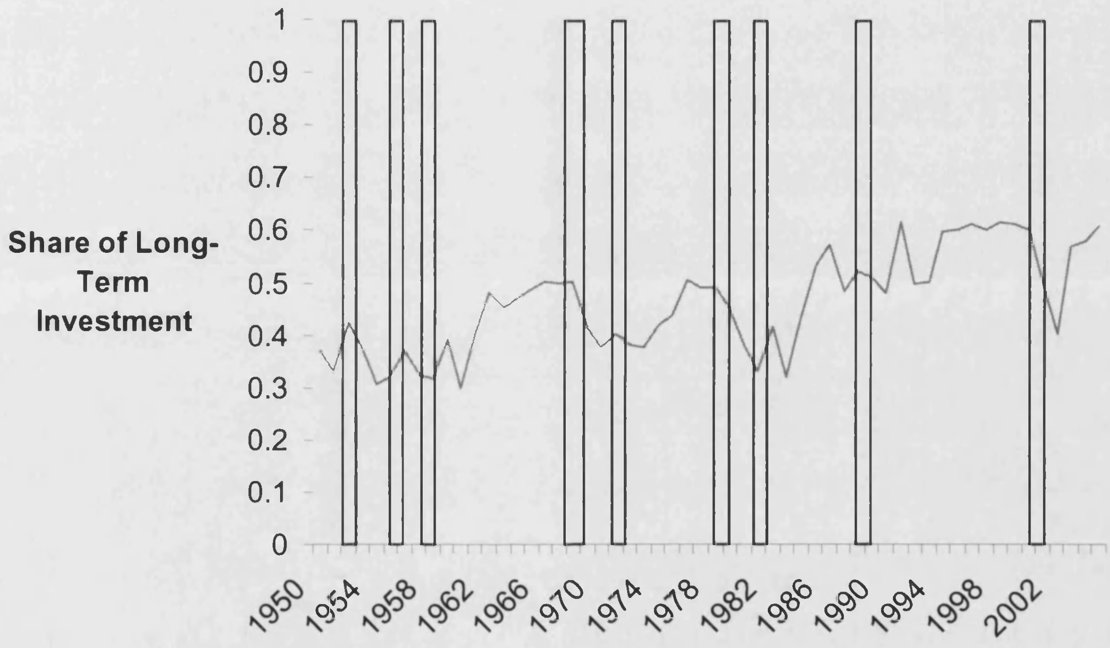

Figure 1.9: Long-Term Investment as a Share of Total Investment (Data for investment for the U.S. from OECD)

long-term structural investment as a share of total investment for firms of all sizes for the U.S. The evidence is not in line with the predictions of this paper, as the graph shows that riskier, long-term investment responds positively to credit conditions. Lack of availability of data disaggregation by firm-size may explain this puzzling result, and I am currently studying this issue further.

Credit Standards are measured as the percent of Loan Officers reporting that they have tightened their credit standards during the past 3 months (Minus percent which have eased), and the composition of investment is calculated according to three different measures:

- Share 1 = (Structures + Residential Investment) / Gross private domestic investment
- Share 2 = (Structures + Residential Investment) / Fixed investment
- Share 3 = Structures / Nonresidential Fixed investment

where gross private domestic investment = Fixed Investment (Structures + Equipment and software + Residential) + Change in private inventories for small firms.

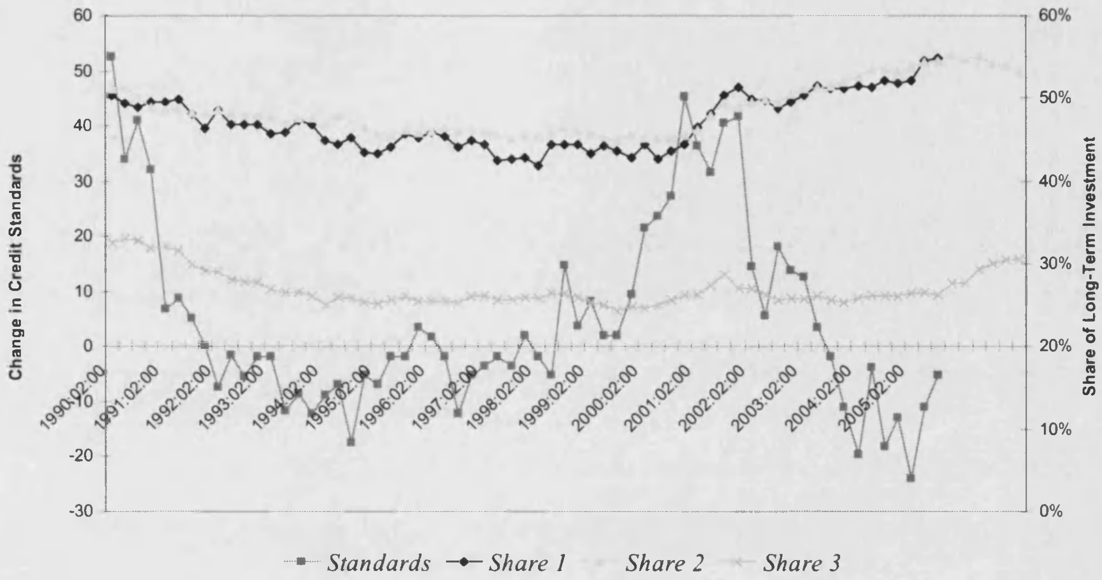

Figure 1.10: Credit Standards and the Share of Long-Term Structural Investment as a Fraction of Total Investment (US Data)

1.7 Discussion and Conclusion

There exists a large body of research on the role of financial frictions in amplifying macroeconomic shocks. Most work has been focused on how firms' *investment capacity* is affected in recessions by tighter borrowing constraints or by a decreased supply of intermediated finance, and has studied how firms are constrained in the amount they can invest ex-post. There has been little focus however on a propagation mechanism that studies how cyclical changes in the risk-sharing capacity of the financial system may be affecting *firms' willingness to bear risk* and acting to propagate the cycle by affecting the risk profile of their investment portfolio (the *composition* as well as the amount).

This paper is motivated by two sets of observations. On the one hand, there is evidence that constrained firms shift the composition of their investment towards safer and more liquid technologies in recessions, while this is not the case for unconstrained firms. On the other hand there is evidence that credit constrained firms display a precautionary behaviour induced by future expected financing constraints that significantly affects their real and financial policies.

Based on these observations, I incorporate these precautionary effects into a dynamic stochastic general equilibrium framework to study their macroeconomic implications. I use this framework to address two important questions. Can a mechanism capturing this precautionary element have significant consequences for aggregate investment and output dynamics? Can this mechanism account for the observed variation in the composition of aggregate and firm-level investment across the business cycle?

This paper identifies a novel amplification mechanism of macroeconomic shocks based on time-varying risk-sharing opportunities that affect firms' preference for the risk profile of their portfolio of investment projects. This amplification mechanism is shown to be quantitatively large and asymmetric. On the other hand, this framework is able to account for the empirically documented cyclical variation in the composition of real investment, a feature which the existing models studying the macroeconomic implications of financial constraints cannot account for. In particular, it is shown how following worsening expected financing conditions, firms shift to safer but lower return investments, or, absent alternative investment opportunities, to liquid securities and cash, and how these effects are stronger for high agency cost firms and for firms in highly volatile industries.

A next step in this research agenda is to study if this mechanism can be potentially enhanced by financial intermediaries' own credit constraints, creating a powerful feedback mechanism between entrepreneurial investment choices, asset prices, and banks' balance sheet conditions and insurance capacity. The ability of financial intermediaries and capital markets to satisfy firms' liquidity demand may itself be subject to similar countercyclical constraints as non-financial firms, creating the potential for feedback effects between firms' investment decisions and intermediaries' balance sheet conditions. A main source of risk and liquidity management for firms are financial intermediaries, both using ex-ante protection through credit lines, and ex-post protection by borrowing on the spot market. Several empirical studies have found that loan supply to small firms is curtailed in downturns and following monetary policy shocks (Gertler and Gilchrist (1993)). The feedback effect through entrepreneurial capital valuations and financial intermediaries' commitment capacity could work as follows. Following a negative aggregate shock, firms increase their demand for ex-ante protection by financial intermediaries through credit lines. Intermediaries, however, are also subject to limited commitment and collateral constraints, and need to back their loan commitments using the loans extended to entrepreneurs as collateral. Intermediaries' ability to provide these loan commitments may decrease both due to lower valuation of existing loans, and lower demand for loans. This introduces a premium on liquidity services by banks, and forces firms to rely even more on operational hedging by adjusting the riskiness of their production technologies, reinforcing the initial effect. This further depresses the valuation of capital, and in turn the valuation of the loan portfolio of banks, further limiting their liquidity commitment capacity. A feedback effect from entrepreneurial investment composition choices to asset prices, loan portfolio valuations and financial intermediaries' liquidity provision capacity arises. The theoretical underpinnings and the quantitative relevance of this extension is left for future research.

1.A Appendix

1.A.1 General Equilibrium - Recursive Equilibrium Conditions

The recursive competitive equilibrium is defined by decision rules for K_{t+1}, C_t, H_t, $\{I_{s,t}^i\}_{i=Y,L,U}$, $\{I_{r,t}^i\}_{i=Y,L,U}$, N_{t+1}^L, N_{t+1}^U, B_t^Y, B_t^L, B_t^U, q_t and r_t, as a function of K_t, θ_t, and $\{N_t^i\}_{i=L,U}$. The recursive equilibrium conditions are given below. First, there is a savings supply decision by households, and a labour supply decision, given respectively by:

$$u_c(t) = \beta E_t \left\{ u_c(t+1) \frac{[q_{t+1}(1-\delta) + \theta_t F_1(t)]}{q_t} \right\}, \tag{1.20}$$

and:

$$\frac{u_L(t)}{u_c(t)} = \theta_t F_2(t). \tag{1.21}$$

The investment good market clearing obtains when the following equation is satisfied:

$$K_{t+1}(q_t) = (1-\delta)K_t + \eta a_s \sum_{i=Y,L,U} \pi^i I_{s,t}^i(q_t) + \eta \frac{a_r}{2} \sum_{i=Y,L,U} \pi^i I_{r,t}^i(q_t),$$

The aggregate resource constraint requires that

$$Y_t = (1-\eta)C_t + \eta C_t^e + \eta \sum_{i=Y,L,U} \pi^i I_{s,t}^i + \eta \sum_{i=Y,L,U} \pi^i I_{r,t}^i + \eta N_t \tag{1.22}$$

The aggregate productivity factor θ follows the stochastic process:

$$\log \theta_{t+1} = \rho \log \theta_t + \sigma_\varepsilon \varepsilon_{t+1} \tag{1.23}$$

1.A.2 Computational Appendix

The equilibrium of this model is solved using the Parameterized Expectations Algorithm (PEA), a method commonly used to solve nonlinear stochastic dynamic models (see Marcet (1988), den Haan and Marcet (1990), and Christiano and Fisher (2000)). It is a non-finite state-space algorithm that approximates the conditional expectation of one or more equilibrium conditions by using a parametric function of the state variables. I have chosen this solution method as it allows me to deal with *(a)* the relatively large number of endogenous state variables (applying discrete state-space methods might be problematic because of the 'curse of dimensionality') and *(b)* the occasionally binding inequality constraints.

To solve this model I need to approximate two expectational equations. First, I approximate the households' euler equation, from which I obtain current period consumption C_t. Second, I also need to approximate the optimality condition of entrepreneurs from which I obtain current period investment in the risky technology by the young entrepreneurs.

For the choice of approximating function for (1.20) I can use homotopy and introduce a function based on the closed form solution that exists for the one-sector stochastic growth model with logarithmic utility and full depreciation. For the second equation I have tried with polynomial functions of different orders, discarding terms for which the explanatory power is small.

The rest of the endogenous variables are calculated each period, where the length of simulation for each iteration is $T = 5,000$. The parameters of the approximating functions are recalculated after each iteration until convergence.

Chapter 2

Aggregate Liquidity and Entrepreneurial Risk

2.1 Introduction

The episode of financial market turbulence in 2007/2008 has highlighted the importance of liquidity for the normal functioning of the financial system. It has shown how even large financial corporations with unparalleled access to capital markets suffer from liquidity shortages, and also how certain assets have a very volatile degree of liquidity. Beyond this casual observation, there is ample evidence that liquidity shortages are often linked to economic slowdowns, and also that liquidity is an important factor for asset pricing. In this paper I focus on how issues of aggregate liquidity affect an arguably more vulnerable set of agents, small and medium sized entrepreneurial firms with limited access to capital markets.

Several recent trends may have affected the relevance of liquidity for investment and output dynamics, and, in order to understand how, it is important to distinguish between the public and the private supply of liquidity. With regards to the public supply of liquidity (*outside liquidity*), the fiscal positions of many countries have improved in recent years, resulting in a decrease in the supply of government debt.[1] With regards to the private supply of liquidity (*inside liquidity*), innovation in the financial sector has changed the availability and characteristics of liquid securities available, an example of which is the recent boom in the securitization of mortgage loans. These recent trends in government finance and in financial development combined have had important effects on financial sector liquidity.

This paper starts by introducing a general equilibrium characterization of liquidity. Firms without investment opportunities demand liquidity to be able to finance future investments, and investing firms create liquidity by issuing claims against their future returns. Additionally, the government issues debt to finance its budget deficits. The contribution of this paper is to analyze the determinants of the supply of private liquidity (inside liquidity) in conjunction with the availability of publicly supplied liquidity, in a model where firms act both as consumers and creators of liquidity.

The first main result of the paper concerns the effect of variations of the public supply of liquidity on steady state investment and capital, and three different channels are identified. On the one hand, an increase in supply decreases the cost for non-investing entrepreneurs of acquiring liquidity, and hence makes self-insurance cheaper and promotes a higher level of investment (the *crowding-in channel*). On the other hand, an increase in supply increases the rate of return on government debt and decreases the demand for equity issued by entrepreneurs, hence decreasing aggregate investment (the *crowding out channel*). Finally, variations in government debt cause a redistribution of wealth between the entrepreneurial sector and workers (the *inter-sectorial redistributive* effect), the sign and strength of which depends crucially on how the taxation that finances the interest cost of that debt is allocated between these two groups of agents.[2]

[1]See figure (2.6) in the appendix, that shows the evolution of US public debt as a share of GDP over the past decades.

[2]In the model, in equilibrium all debt is held by entrepreneurs, so increases in debt when the real rate of return is positive and entrepreneurs are not fully taxed for the interest cost of that debt result in a transfer between workers and entrepreneurs. This should not be confused with the redistributive effect of government debt variations *within the entrepreneurial sector;* those transfers are the essence of the

I show that when comparing in isolation the first two channels, the crowding-in effect dominates when the degree of financial frictions is high (low borrowing capacity and low liquidity of equity of entrepreneurs), and vice-versa. In other words, additional liquidity is most valuable when borrowing constraints are tight and equity is very illiquid. Absent financial frictions, the crowding-out effect dominates. The redistributive effect is shown to be ambiguous in general. It is most likely to be negative (i.e. for increases in debt to transfer wealth from entrepreneurs to workers) when financial frictions are severe and government debt carries a liquidity premium large enough to justify negative real rates of return to government debt. Two scenarios are identified in which, when considering the three channels together, the effects of government debt on aggregate investment are non-monotonic (reducing investment for low values of debt-to-GDP, and increasing investment beyond a threshold).

The second set of results concerns the asset pricing implications of the model. The features of the model introduced, and in particular those related to liquidity, that can bring us closer to resolving some of the main ongoing asset pricing puzzles are identified. The debt-to-GDP ratio, the degree of financial constraints, and the liquidity of equity are shown to significantly affect asset prices, and I also show which parameter conditions are needed to match the observed asset pricing facts better. In particular, I show that there is a negative relationship between the debt-to-GDP ratio and the equity premium, which can help understand the reduction in the equity premium in recent decades.

Finally, I study how variations in the determinants of liquidity affect an economy's response to productivity and liquidity shocks. The contemporaneous response of aggregate investment and output to productivity shocks is larger in economies with lower levels of government debt. Firms rely to a greater extent on equity for self-insurance, the supply of which endogenously co-moves with the cycle and acts to amplify the

crowding-in effect, as they allow a better allocation of resources to investing entrepreneurs.

effect of shocks. The model also offers a new explanation for the documented countercyclical pattern of the equity premium. Equities provide a worse hedge against the risk of having an investment opportunity and being liquidity constrained in a downturn than do government bonds, and hence agents holding equities require a higher premium in downturns. I also study the effect of liquidity shocks, and show that shocks to the liquidity of firms' equity affect investment and output to a greater extent in economies with a low level of government debt.

Literature Review

This paper is related to various strands of the literature. It builds on the literature studying the effects of the public supply of liquidity on private investment, such as Woodford (1990) and Holmstrom and Tirole (1998). The differences with both are important. In Woodford, the private supply of liquidity is not considered by assuming that entrepreneurs cannot borrow at all, and the only means of saving for non-investing entrepreneurs is government debt. Holmstrom and Tirole (1998) do consider the private supply of liquidity, but in a context where there is no channel through which government-supplied liquidity can crowd-out private investment. Additionally, in both papers, there is only one type of agent, entrepreneurs, and hence the issue of the redistribution of wealth through government debt and taxation between different sectors of the economy (workers and entrepreneurs in my framework) cannot be studied.

This paper is also related to the recent research that explores the asset pricing implications of production-based models. Cochrane (1991) and (1996) shows that such a model can fit the data better than a standard consumption-based model. His model however assumes complete markets, unlike this one, and hence does not study issues of liquidity. A more recent contribution is Jermann (2008), whose analysis is similar to Cochrane's and does not consider the role of financial frictions. Gomes, Yaron, and Zhang (2006) is an empirical study of the significance of factors related to firms' financial constraints in explaining the cross-section of equity returns. Finally, a closely related paper is Holmstrom and Tirole (2001), which is a theoretical study that tries to bridge the gap between corporate finance and asset pricing.

This paper also builds on the literature studying the aggregate implications of endogenous borrowing constraints, with papers such as Bernanke and Gertler (1989), Kiyotaki and Moore (1997), and Bernanke, Gertler and Gilchrist (2000), and particularly to Kiyotaki and Moore (2008), who also study the effects of liquidity on investment and capital accumulation. In particular, the model in this paper builds on Kiyotaki and Moore (2008) by extending their framework to include government debt.

2.2 Model

Consider an infinite-horizon, stochastic, discrete time economy with three agents: entrepreneurs, workers and a government. There are two goods in this economy, consumption goods and capital goods. All entrepreneurs can produce consumption goods using labour from the workers and capital, but only some entrepreneurs have the opportunity to produce capital in a given period. One important ingredient in the model is that the combination of financial constraints and the stochastic arrival of investment opportunities creates a demand for liquidity, and this demand can only be met by holding government debt and entrepreneurial equity.

I will now analyze separately the optimization of entrepreneurs and workers and the behaviour of the government.

2.2.1 Entrepreneurs

There is a continuum of entrepreneurs with expected lifetime utility

$$E_0 \sum_{t=0}^{\infty} \beta^t u(c_t),$$

where $0 < \beta < 1$ and $u(c) = \ln c$.

Production Technologies

Entrepreneurs have access to two production technologies. On the one hand they can, *every period*, produce consumption goods using labour and capital according to the production function

$$y_t = a_t k_t^{\alpha} l_t^{1-\alpha},$$

where $0 < \alpha < 1$, and a_t is a stochastic productivity factor which is equal across entrepreneurs. Entrepreneurs do not have any labour endowment, and hire workers at the market rate w_t for that purpose.

On the other hand, entrepreneurs also have access *occasionally* to a technology that converts i_t units of the consumption good into capital one-for-one to be used the following period. Total capital next period is thus

$$k_{t+1} = (1-\delta)k_t + i_t,$$

where δ is the rate of depreciation of capital. The opportunity to produce capital is not available every period to every entrepreneur, and arrives only with probability π in any given period, and this arrival is independently distributed across entrepreneurs and time.

Financial Constraints and Demand for Liquidity

Entrepreneurs can finance themselves by issuing equity e_t. From the point of view of the agent purchasing that equity, the rate of return from purchasing one unit at price q_t is $[r_{t+1} + (1-\delta)q_{t+1}]$, where $r_{t+1} = a_{t+1}\alpha k_{t+1}^{\alpha-1} l_t^{1-\alpha}$. Effectively, the purchase of one unit of equity gives the same return as the purchase of one unit of capital, which will also produce a return the following period of $r_{t+1} + (1-\delta)q_{t+1}$. Another way to see this is that all equity is fully collateralized using capital, and hence provides the same return as capital. For this reason from now on we will consider capital and *outside* equity as the same for the purposes of entrepreneurs' choices, denote it n_t and call it "*equity*".

Equity issuance by entrepreneurs is subject to financial constraints. More specifically, entrepreneurs can only pledge a fraction θ of the returns to investment. [3]

$$e_t \leq \theta i_t \tag{2.1}$$

The budget constraint for an *investing* entrepreneur (denoted with superscript i) in period t is thus:

$$c_t^i + i_t + \tau_t^i = r_t n_t + q_t\{(1-\delta)n_t - [n_{t+1}^i - (i_t - e_t^i)]\} + \left(b_t - \frac{b_{t+1}^i}{1+r_{t+1}^g}\right) + q_t e_t^i, \tag{2.2}$$

where b_t^i are the holdings of government debt of an investing entrepreneur, which becomes payable at the beginning of period t. New government debt b_{t+1}^s can be purchased at price $1/(1+r_{t+1}^g)$, where r_{t+1}^g is the rate of return on government treasuries. The reason the predetermined variables (such as n_t) do not carry a superscript is that they may refer both to an entrepreneur who was a saver or an investor in the previous period.

The budget constraint for a non-investing entrepreneur (*saver*, denoted with superscript s) in period t is thus:

$$c_t^s + \tau_t^s = r_t n_t + q_t[(1-\delta)n_t - n_{t+1}^s - e_t^s] + \left(b_t - \frac{b_{t+1}^s}{1+r_{t+1}^g}\right) + q_t e_t^s. \tag{2.3}$$

Expression (2.3) can be simplified if we take into account that equity owned and equity issued pay the holder the same return, and can thus be netted out. Taking this into account, and rearranging terms, we have:

[3] For a rationale for this type of collateral constraint see Hart and Moore (1994).

$$c_t^s + \tau_t^s + \frac{b_{t+1}^s}{1 + r_{t+1}^g} + q_t n_{t+1}^s = r_t n_t + q_t(1-\delta)n_t + b_t.$$

Optimization of an Investing Entrepreneur

In a similar way to Tobin's q-theory of investment, whenever $q_t > 1$, an investing entrepreneur will want to invest as much as possible to produce capital goods, given that producing capital costs one unit of the consumption good. When $q_t < 1$, it is not profitable to issue equity to invest. The parameter conditions under which $q_t > 1$ obtains are in the Appendix.

When this is the case, then $e_t = \theta i_t$, $n_{t+1}^i = (1-\theta)i_t$ and $b_{t+1}^s = 0$. Taking this into account, and substituting i_t out of expression (2.2) we get:

$$c_t^i + q_t n_{t+1}^i + \tau_t^i = r_t n_t + q_t(1-\delta)n_t + b_t.$$

Given logarithmic preferences, consumption is equal to a fraction $(1-\beta)$ of wealth:

$$c_t^i = (1-\beta)\left\{r_t n_t + q_t(1-\delta)n_t + b_t - \tau_t^i\right\}, \tag{2.4}$$

and investment will be equal to:

$$\begin{aligned} i_t &= \frac{[r_t n_t + q_t(1-\delta)n_t + b_t - \tau_t^i] - c_t^i}{1-\theta q_t} \\ &= \frac{\beta\left[r_t n_t + q_t(1-\delta)n_t + b_t - \tau_t^i\right]}{1-\theta q_t} \end{aligned} \tag{2.5}$$

Optimization of a Saving Entrepreneur

Entrepreneurs that do not have an investment opportunity face two choices: a consumption/savings choice, and a portfolio choice.

As before, their consumption every period will be equal to a fraction $(1-\beta)$ of wealth, and hence be equal to:

$$c_t^s = (1-\beta)\left[r_t n_t + q_t(1-\delta)n_t + b_t - \tau_t^s\right] \tag{2.6}$$

Their first order conditions with regards to the choice of entrepreneurial equity and government debt holdings are respectively:

$$\begin{aligned} u'(c_t^s) &= \pi E_t\left\{u'(c_{t+1}^i)\frac{r_{t+1}+q_{t+1}(1-\delta)}{q_t}\right\} && (2.7)\\ &\quad +(1-\pi)E_t\left\{u'(c_{t+1}^s)\frac{r_{t+1}+q_{t+1}(1-\delta)}{q_t}\right\} && (2.8)\end{aligned}$$

and

$$u'(c_t^s) = E_t\left\{(1+r_{t+1}^g)[\pi u'(c_{t+1}^i) + (1-\pi)u'(c_{t+1}^s)]\right\} \tag{2.9}$$

2.2.2 Workers

There is a continuum of workers with expected lifetime utility

$$E_0\sum_{t=0}^{\infty}\beta^t u\left[c_t^w - \frac{\omega}{1+v}(l_t^w)^{1+v}\right],$$

where $0<\beta<1$, $u'(.)>0$, $u''(.)<0$, $\omega>0$ and $v>0$. The budget constraint of workers is given by

$$c_t^w + q_t n_{t+1}^w + \frac{b_{t+1}^w}{1+r_{t+1}^g} + \tau_t^w = w_t l_t^w + r_t n_t^w + q_t n_t^w + b_t^w$$

where τ_t is lump sum taxation. Simple optimization delivers:

$$\begin{aligned} l_t^w &= \left(\frac{w_t}{\omega}\right)^{\frac{1}{v}} && (2.10)\\ c_t^w &= w_t l_t^w. && (2.11)\end{aligned}$$

Workers' consumption is equal to their wage income each period (expression (2.11)), and the appendix shows why in the neighborhood of the steady state workers choose not to hold any equity or government debt.

2.2.3 Government

The role of government is simplified by assuming there is no government spending. It is just assumed to follow a target of total amount of one-period government debt B which it rolls over every period, where:

$$B = \int b_{t+1}^{s} d\Phi_t(s),$$

and where $\Phi_t(s)$ is the distribution function of saving entrepreneurs in period t. Every period, the government balances its budget by financing the interest rate cost of this debt with lump-sum taxation:

$$\left(1 - \frac{1}{1 + r_t^g}\right) B = \frac{r_t^g}{1 + r_t^g} B = \pi \tau_t^i + (1 - \pi)\tau_t^s + \tau_t^w, \tag{2.12}$$

where τ_t^i, τ_t^s and τ_t^w are respectively the lump-sum taxes charged to investing entrepreneurs, saving entrepreneurs, and workers, which are weighted in expression (2.12) by their population share. The assumption of how the tax-burden is distributed is not innocuous, and the results in the following sections are robust to all possible assumptions.

2.3 General Equilibrium

Aggregation is made easy because the policy functions for consumption, investment and portfolio decisions are all linear in start of period holdings of government debt and equity. Furthermore, given that the process driving investment opportunities is independently distributed across time and entrepreneurs, we can drop references to aggregate equity N_t, and instead always refer to capital, given that in the aggregate $N_t = K_t$. The distinction will be kept, however, for savers' future period net worth, N^s_{t+1}, for reasons that will become clear later.

The aggregate resource constraint for this economy is

$$Y_t = C^i_t + C^s_t + C^w_t + I_t, \tag{2.13}$$

where C^i_t, C^s_t and C^w_t are respectively the aggregate consumption of investing entrepreneurs, saving entrepreneurs, and workers, and are given by:

$$\begin{aligned} C^i_t &= \pi(1-\beta)\left\{r_t K_t + q_t(1-\delta)K_t + B - \tau^i_t\right\} && (2.14)\\ C^s_t &= (1-\pi)(1-\beta)\left\{r_t K_t + q_t(1-\delta)K_t + B - \tau^s_t\right\} && (2.15)\\ C^w_t &= w_t - \tau^w_t, && (2.16)\end{aligned}$$

where $r_t = \alpha a_t K_t^{\alpha-1}$.

The aggregate resource constraint becomes, after rearranging:

$$\begin{aligned} &\alpha a_t K^\alpha_t + \frac{r^g_t}{1+r^g_t}B - \left[\pi\tau^i_t + (1-\pi)\tau^s_t + \tau^w_t\right] && (2.17)\\ = \;& I_t + (1-\beta)\left\{r_t K_t + q_t(1-\delta)K_t + B_t - \left[\pi\tau^i_t + (1-\pi)\tau^s_t\right]\right\} + (w_t - \tau^w_t) \end{aligned}$$

Where $I_t = K_{t+1} - (1-\delta)K_t$.The expression for investment is:

$$I_t = \frac{\pi\beta[r_t K_t + q_t(1-\delta)K_t + B_t - \tau^i_t]}{1-\theta q_t} \tag{2.18}$$

Finally, the expression for aggregate portfolio choices of the saving entrepreneurs is:

$$E_t\left\{\frac{[r_{t+1}+q_{t+1}(1-\delta)]/q_t}{[r_{t+1}+q_{t+1}(1-\delta)]N^s_{t+1}+B_{t+1}}\right\} \tag{2.19}$$
$$= E_t\left\{\frac{(1+r^g_{t+1})}{[r_{t+1}+q_{t+1}(1-\delta)]N^s_{t+1}+B_{t+1}}\right\}.$$

Proofs for existence and uniqueness of a competitive equilibrium in the neighborhood of the steady state are contained in the appendix.

2.4 Public Supply of Liquidity and Private Investment

In this section I will analyze the effects of changes in the aggregate amount of government debt on entrepreneurs' investment in the steady state. Accordingly, I drop time subscripts in all variables in this section. The steady state equilibrium can be obtained by solving the following three equilibrium conditions for q, r^g and K:

$$\alpha a K^{\alpha}+\frac{r^g}{1+r^g}B-\left[\pi\tau^i+(1-\pi)\tau^s+\tau^w\right]=\delta K \tag{2.20}$$
$$+(1-\beta)\left\{\alpha a K^{\alpha}+q(1-\delta)K+B-\left[\pi\tau^i+(1-\pi)\tau^s\right]\right\} \tag{2.21}$$

$$(1-\theta q)\delta K=\pi\beta[\alpha a K^{\alpha}+q(1-\delta)K+B-\tau^i] \tag{2.22}$$

$$[\alpha a K^{\alpha-1}+q(1-\delta)]/q=(1+r^g). \tag{2.23}$$

Expression (2.20) is the aggregate resource constraint, (2.22) is the aggregate investment equation, and finally (2.23) is the aggregate portfolio equation.

A study of these equilibrium conditions reveals that in this economy there are *three* *channels* through which an increase in government debt affects aggregate investment. First, it relaxes investing entrepreneurs' borrowing constraints and increases investment. This is the *crowding-in* effect, and is captured in expression (2.22). Second, it increases the rate of return on government debt and decreases demand for entrepreneurial equity from saving entrepreneurs, thus reducing investment. This is the *crowding-out* effect, and is captured in the aggregate version of the portfolio choice equation (expression (2.22)), and in the aggregate resource constraint (2.20).

Finally, an increase in government debt may vary the transfers between the government and the entrepreneurial sector, and between the government and the workers (the *inter-sectorial redistributive* effect). For example, if entrepreneurs pay no taxes (they are fully paid by workers), and the government increases its borrowing, then the transfers between the government and entrepreneurs increase, assuming the interest rates on government securities are positive. Effectively it implies an indirect transfer of wealth from workers to entrepreneurs. This should not be confused with the redistributive effect of government debt variations *within the entrepreneurial sector;* those transfers are the essence of the crowding-in effect, as they allow a better allocation of resources to investing entrepreneurs.

2.4.1 Crowding-in versus crowding-out

We will start by performing an analytical study of the first two channels only by abstracting from the inter-sectorial redistributive channel. In order to do so, I will study a particular case of the model introduced in the previous section. *First,* I assume that all taxes are paid for by the saver-entrepreneurs:

$$(1-\pi)\tau^s = \frac{r^g}{1+r^g}B \tag{2.24}$$

$$\tau^i = 0 \tag{2.25}$$

$$\tau^w = 0. \tag{2.26}$$

Secondly, I assume that there is no idiosyncratic uncertainty and that for every entrepreneur an investment opportunity arises every other period with certainty. In particular, every period half of the entrepreneurs have an investment opportunity, and the other half save in advance of their investment opportunity the following period, a set-up which follows Woodford (1990). *Finally*, I make a particular assumption on how the taxes are paid for. The lump-sum taxes are paid by saver-entrepreneurs when they purchase government debt. It could be interpreted as a fixed participation cost; as the cost to be able to trade in government treasuries.[4] Given these assumptions, the aggregate resource constraint (2.20) simplifies to:

$$\alpha a K^{\alpha} = \delta K + (1-\beta)\left\{\alpha a K^{\alpha} + q\frac{(1-\delta)}{2}K + B\right\}, \tag{2.27}$$

and the investment equation becomes

$$(1-\theta q)\delta K = \frac{1}{2}\beta[\alpha a K^{\alpha} + q(1-\delta)K + B] \tag{2.28}$$

We are ready to assess the relative importance of the crowding-in and crowding-out effects.

Proposition 2.1 *When the redistributive effects of government debt variations are ignored, the effects of variations in government debt on aggregate investment in the steady state are monotonic. In particular, the crowding-in(out) effect dominates the crowding-out(in) effect for low(high) values of θ (borrowing constraints are tight(loose)).*

Proof of this proposition in the appendix.

[4]Given this assumption, these taxes are not taken into account to calculate beginning of period wealth and hence consumption. Also, by the assumption that they are lump-sum, they do not enter the portfolio equation and do not distort the portfolio decision. Finally, given that the government sets taxes to finance the interest cost of debt every period, returns to government debt and taxes cancel each other in the aggregate resource constraint (2.20).

Assuming that there is no idiosyncratic uncertainty eliminates the possibility that, given lump-sum taxation, entrepreneurs with very low levels of net worth may end up with negative consumption.

■

The intuition for this proposition is as follows. Additional liquidity is most valuable when borrowing constraints are tight, which happens when θ is low. In the other extreme, when credit constraints are so loose that entrepreneurs invest close to the unconstrained optimum, additional liquidity has little scope to improve a situation in which liquidity demand is well satisfied. Instead, most of the effect of the increase in government debt arises because it competes with privately supplied liquidity for savers' funds, and hence crowds out private equity and investment.

I also conduct some analytical exercises to get a better understanding of the relative effects of the crowding-in and crowding-out channels. Again focusing on the case in which the intersectorial redistribution channel is shut off, proposition 1 tells us that variations in the amount of debt cause monotonic variations in the level of steady-state capital. Indeed, if we observe figure (2.1) this is the case. Low values of the financial constraint θ, in other words tighter credit constraints, are associated with a net positive effect of government debt on steady state capital. The turning point in the base calibration occurs for values around $\theta = 0.45$, after which the crowding-out effect begins to dominate.[5]

2.4.2 Crowding-in, crowding-out and the redistributive channel

Now we are in a position to add to the analysis the *inter-sectorial redistributive* effect in the case in which the financing costs of government debt (which is held in its entirety by the entrepreneurial sector) are not fully paid with the entrepreneurial taxes, but instead workers' taxes pay for a fraction of those costs. We drop the three assumptions of subsection 2.4.1 and instead we are back to the original model only that

[5]Similar results are obtained when looking at comparative statics when the degree of liquidity ϕ varies, in the model of the next section where imperfect resaleability of equity is introduced (see figure (2.7) in the Appendix).

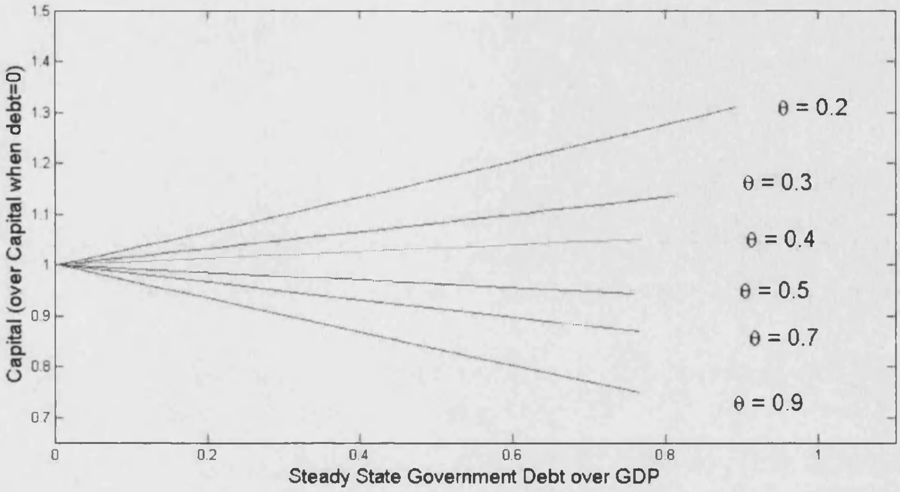

Figure 2.1: Effect of Variations in the Ratio of Debt to GDP on the Level of Capital, for Different Levels of Financial Constraints, when all Taxes are Paid for by Saving Entrepreneurs (i.e. when not taking into account the inter-sectorial distributive effects).

now we are going to assume that workers now pay all taxes, so:

$$\tau^s = 0, \tag{2.29}$$

$$\tau^i = 0, \tag{2.30}$$

$$\tau^w = \frac{r^g}{1+r^g}B. \tag{2.31}$$

It is easy to show that the effects on investment of the inter-sectorial redistributive channel are ambiguous in general. Denoting transfers between workers and entrepreneurs induced by government debt and taxation by $z(B)$, these are equal to:

$$z(B) = \frac{r^g}{1+r^g}B,$$

and the sensitivity of transfers to variations in the amount of B is

$$z'() = \frac{1}{1+r^g}\left[r^g + \frac{dr^g}{dB}\frac{B}{1+r^g}\right].$$

When entrepreneurs pay no taxes, the distributive effect can be positive (from the point of view of entrepreneurs) or negative: positive when $r^G > 0$, and positive or negative when $r^G < 0$. Increases of government debt will always increase r^G, which opens the possibility for non-monotonic effects when for low values of B, $r^G < 0$ and the redistribution effect is negative, and beyond a threshold in the admissible parameter range for B, $r^G > 0$ (and hence the redistribution effect is negative).

So, when the *three channels* are taken into account, and if as a result the effects of variations in government debt on aggregate investment in the steady state are non-monotonic, then they are such that increases in government debt reduce(boost) aggregate investment for low(high) levels of government debt. We now conduct some numerical exercises to help us understand how the three channels interact with each other, always under the assumption described above that the redistribution between workers and entrepreneurs is at its potential maximum, which happens when workers pay all taxes. The analysis is done for empirically plausible ranges of government debt-to-GDP, which range from 20% to 100% for most countries.[6]

The results are in figure (2.2). As explained above the redistributive effects are ambiguous in general: in particular, they might be positive or negative when $r^g < 0$, which happens for low values of B, and are always positive when $r^g > 0$. The results in figure (2.2) suggest that the non-monotonicity is strongest when θ is tightest. Bearing in mind our analytical results above, and inspecting the behaviour of the rate of return to government debt in the numerical exercises, the reason for these results can be found in the way that financial factors affect the sign and strength of the redistributive effect. In particular, it is for low values of θ that the liquidity premium on government debt is highest, and hence for which the return on government debt r^g may be negative. For that reason, any negative redistributive effects are likely to happen for low values of θ. So, the crowding-out effects that seem to be present only when credit constraints

[6]See Jaimovich and Panizza (2006).

are tight (which seems to contradict Proposition 1) are entirely due to the inter-sectorial redistributive effect. A similar, but less strong result is obtained when varying the degree of liquidity of equity (see figure (2.8)).

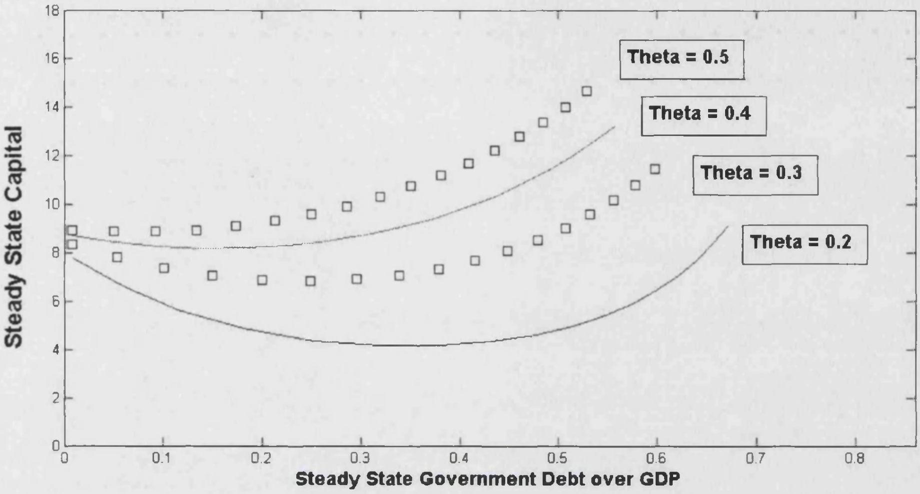

Figure 2.2: Effect of Variations in the Ratio of Debt to GDP on the Level of Capital, for Different Levels of Financial Constraints, when all Taxes are Paid for by Workers (i.e. when taking into account the inter-sectorial distributive effects).

Two comments are in order when interpreting the behaviour of capital for high values of debt-to-GDP. In figure 2.2, steady state capital rise dramatically for values of debt-to-GDP approaching unity. This is due to two effects. First, the redistributive channel is positive and strongest at those levels, when the entrepreneurial sector is forced to hold a large amount of government debt and have to be compensated with a very high return r^g for it. And second, given that we are comparing steady state capital to debt-to-GDP, the denominator of the ratio of debt-to-GDP is also increasing at a large pace, such that the debt increases needed to increase the ratio become larger. It is important to note that the redistributive channel has a natural limit in that the wealth of the workers is limited, and secondly that even before it reaches its limit it is not realistic to assume the government would sustain such large systematic redistributions between the workers and the entrepreneurial sector.

2.5 A Model with Stochastic Liquidity of Equity

The previous sections have analyzed a model where both equity and government debt had the same degree of resaleability (liquidity). Introducing a wedge between the resaleability of both types of assets does not affect the results of studying to what extent financial frictions influence how the public supply of liquidity affects the private creation of liquidity and private investment by firms in the *long run*. To study the dynamics of this economy, however, it is interesting to consider a time-varying degree of liquidity of equity. Indeed, on the one hand it makes the model more realistic as we observe in reality that certain assets have a very volatile degree of liquidity. Pulvino (1998) documents a 30% price discount for commercial aircraft sales in depressed markets and Coval and Stafford (2007) report an average 7.9% price discount for fire sale stocks. The latter is particularly significant given that we consider that equities are amongst the most liquid assets. On the other hand, introducing time-varying liquidity of equity allows us to study the effects of exogenous shocks to liquidity.

The model is the same as before, only that now I assume that equity has limited resaleability, and only a fraction ϕ of equity can be *sold or re-mortgaged* each period.

$$(1-\delta)n_t - [n^i_{t+1} - (i_t - e^i_t)] \leq \phi(1-\delta)n_t \tag{2.32}$$

The assumptions on limited resaleability and limited pledgeability (the combination of expressions (2.32) and (2.1) above) imply the following liquidity constraints for an investing entrepreneur:

$$\begin{aligned} n^i_{t+1} &\geq (1-\phi)(1-\delta)n_t + (1-\theta)i_t \\ b^i_{t+1} &\geq 0, \end{aligned}$$

Similarly as before, whenever $q_t > 1$, then $e_t = \theta i_t$, $n^i_{t+1} = (1-\phi)(1-\delta)n_t + (1-$

$\theta)i_t$ and $b^s_{t+1} = 0$. Taking this into account, and substituting i_t out of expression (2.2) we get:

$$c^i_t + q^R_t n^i_{t+1} + \tau^i_t = r_t n_t + [\phi q_t + (1-\phi)q^R_t](1-\delta)n_t + b_t,$$

where

$$q^R_t \equiv \frac{1-\theta q_t}{1-\theta}.$$

Given logarithmic preferences, consumption is equal to a fraction $(1-\beta)$ of wealth:

$$c^i_t = (1-\beta)\left\{r_t n_t + [\phi q_t + (1-\phi)q^R_t](1-\delta)n_t + b_t - \tau^i_t\right\}, \tag{2.33}$$

and investment will be equal to:

$$\begin{aligned} i_t &= \frac{[r_t n_t + \phi q_t(1-\delta)n_t + b_t - \tau^i_t] - c^i_t}{1-\theta q_t} \\ &= \frac{\beta\,[r_t n_t + \phi q_t(1-\delta)n_t + b_t - \tau^i_t] - (1-\beta)(1-\phi)q^R_t](1-\delta)n_t}{1-\theta q_t} \end{aligned} \tag{2.34}$$

The saving entrepreneur, on the other hand, is subject to the following constraints:

$$\begin{aligned} n^s_{t+1} &\geq (1-\phi)(1-\delta)n_t \\ b^s_{t+1} &\geq 0. \end{aligned}$$

As before, entrepreneurs that do not have an investment opportunity face again two choices: a consumption/savings choice, and a portfolio choice. As before, their consumption every period will be equal to a fraction $(1-\beta)$ of wealth, and hence be equal to:

$$c^s_t = (1-\beta)\,[r_t n_t + q_t(1-\delta)n_t + b_t - \tau^s_t] \tag{2.35}$$

Their first order conditions with regards to the choice of entrepreneurial equity and government debt holdings are respectively:

$$u'(c_t^s) = \pi E_t\left\{u'(c_{t+1}^i)\frac{r_{t+1}+[\phi q_{t+1}+(1-\phi)q_{t+1}^R](1-\delta)}{q_t}\right\} \tag{2.36}$$
$$+(1-\pi)E_t\left\{u'(c_{t+1}^s)\frac{r_{t+1}+q_{t+1}(1-\delta)}{q_t}\right\} \tag{2.37}$$

and

$$u'(c_t^s) = E_t\left\{(1+r_{t+1}^g)[\pi u'(c_{t+1}^i)+(1-\pi)u'(c_{t+1}^s)]\right\} \tag{2.38}$$

2.5.1 General Equilibrium with Stochastic Liquidity of Equity

The aggregate resource constraint for this economy is now:

$$\begin{aligned}&\alpha a_t K_t^\alpha + \frac{r_t^g}{1+r_t^g}B - \left[\pi\tau_t^i + (1-\pi)\tau_t^s + \tau_t^w\right]\\ = \;& I_t + (1-\beta)\left\{r_t K_t + [(1-\pi+\pi\phi)q_t + \pi(1-\phi)q_t^R](1-\delta)K_t + B_t - \left[\pi\tau_t^i + (1-\pi)\tau_t^s\right]\right\}\cdot\end{aligned}$$

where $I_t = K_{t+1} - (1-\delta)K_t$.The expression for investment is:

$$I_t = \frac{\pi\{\beta[r_tK_t + \phi q_t(1-\delta)K_t + B_t - \tau_t^i] - (1-\beta)(1-\phi)q_t^R(1-\delta)K_t\}}{1-\theta q_t} \tag{2.40}$$

Finally, the expression for aggregate portfolio choices of the saving entrepreneurs is:

$$\begin{aligned}&(1-\pi)E_t\left\{\frac{[r_{t+1}+q_{t+1}(1-\delta)]/q_t - (1+r_{t+1}^g)}{[r_{t+1}+q_{t+1}(1-\delta)]N_{t+1}^s + B_{t+1}}\right\}\\ = \;& \pi E_t\left\{\frac{(1+r_{t+1}^g) - [r_{t+1}+[\phi q_{t+1}+(1-\phi)q_{t+1}^R](1-\delta)]/q_t}{[r_{t+1}+[\phi q_{t+1}+(1-\phi)q_{t+1}^R](1-\delta)]N_{t+1}^s + B_{t+1}}\right\}.\end{aligned} \tag{2.41}$$

Proofs for existence and uniqueness of a competitive equilibrium in the neighborhood of the steady state are contained in the appendix.

2.5.2 Crowding-in versus crowding-out - Comparative Statics with Limited Liquidity of Equity

When we add limited liquidity of equity, the steady state equilibrium conditions become:

$$\begin{aligned} & \alpha a K^{\alpha} + \frac{r^g}{1+r^g}B - \left[\pi\tau^i + (1-\pi)\tau^s + \tau^w\right] \\ = \quad & \delta K + (1-\beta)\left\{\alpha a K^{\alpha} + [(1-\pi+\pi\phi)q + \pi(1-\phi)q^R](1-\delta)K + B - \left[\pi\tau^i + (1-\pi)\tau^s\right]\right\} \end{aligned} \tag{2.42}$$

$$(1-\theta q)\delta K = \pi\{\beta[\alpha a K^{\alpha} + \phi q(1-\delta)K + B - \tau^i] - (1-\beta)(1-\phi)q^R(1-\delta)K\} + (w - \tau^w) \tag{2.43}$$

$$\begin{aligned} & (1-\pi)\frac{[\alpha a K^{\alpha-1} + q(1-\delta)]/q - (1+r^g)}{[\alpha a K^{\alpha-1} + q(1-\delta)]\Gamma K + B - \tau^s} \\ = \quad & \pi\frac{(1+r^g) - [\alpha a K^{\alpha-1} + [\phi q + (1-\phi)q^R](1-\delta)]/q}{[\alpha a K^{\alpha-1} + [\phi q + (1-\phi)q^R](1-\delta)]\Gamma K + B - \tau^i}. \end{aligned} \tag{2.44}$$

where $\Gamma = (1-\pi)(1-\delta) + \phi\pi(1-\delta) + \theta\delta$,and $q^R = (1-\theta q)/(1-\theta)$. (2.42) is the aggregate resource constraint, (2.43) is the aggregate investment equation, and finally (2.44) is the aggregate portfolio equation. Proposition 2.1 can now be extended as follows:

Proposition 2.2 *When the redistributive effects of government debt variations are ignored, the effects of variations in government debt on aggregate investment in the steady* *state are monotonic. In particular, the crowding-in(out) effect dominates the crowding-out(in) effect for (1) low(high) values of θ (borrowing constraints are tight(loose)), and (2) low(high) values of ϕ (equity has a limited(ample) liquidity).*

Proof of this proposition in the appendix.

■

2.6 Dynamics

We now introduce aggregate uncertainty in the economy to analyze the consequences of the liquidity-related financial frictions studied in this model for two issues: for asset pricing and for the response of aggregate investment and output to technology and liquidity shocks. The main question is which (if any) of the novel elements of the economy analyzed are relevant for bringing us closer to matching certain important asset pricing empirical regularities, and also for bringing us closer to matching the response to shocks of both real and financial variables.

The model is calibrated as follows. The length of a period is a quarter, and all parameters are calibrated to U.S. post-war data.[7] With regards to preference parameters, the rate of time preference $\beta = 0.99$ as is standard in the literature, and the degree of relative risk aversion for entrepreneurs is constant and set at unity given our assumption of log-utility. Workers' preference parameters are all subsumed in the total factor productivity a_t, given our assumption that workers consume all of their wage income, and a_t is set to match an average return on equity of 6.98% (data from Alvarez and Jermann (2001)). Out of the remaining technology parameters, depreciation rate δ is set at a quarterly rate of 2.5%, and the capital share of output, α is set at 36%. The relative size of investing entrepreneurs as a share of the total population of entrepreneurs, π,

[7]In the different comparative exercises in which some of these parameters are varied, all other parameters that are set to match a target are also adjusted to keep matching that target.

is set to match the average rate of investment to GDP (excluding government expenditures) of 25% (data from Uhlig (2006)). The aggregate supply of government bonds B is set to match the average value of US Treasury securities held by the US public as a share of GDP (38%, obtained from Gomes and Michaelides (2008) in data taken from the Congressional Budget Office). Regarding taxes, entrepreneurs pay a 35% tax rate on their returns from government debt, while workers pay the residual to balance the government budget. The parameters relating to financial imperfections are calibrated as follows. The borrowing constraint θ is set to match the average ratio of capital market capitalization to GDP of 1.3 between 1970 and 2001 (Hobijn and Jovanovic (2001)). The calibration of the liquidity of corporate equity is not straightforward. For lack of a better option, I set at around $\phi \approx 0.5$ to loosely match the fraction of illiquid equity in the economy, given that in the U.S. about half of private investment and employment is associated to privately owned firms. Under the assumption that one would purchase a perfectly diversified portfolio of the entire private sector, this would roughly translate into a degree of liquidity of about one-half. In any event, in the numerical exercises I check that this choice of parameter value is not crucial for any particular result, and where it is I indicate it. Finally, the source of aggregate uncertainty in this economy, the productivity process, is parameterized as $\rho = 0.95$ and σ^2 chosen to match the volatility of aggregate output in the data, where the stochastic process is

$$\begin{aligned} \log(z_t) &= \rho \log(z_{t-1}) + \varepsilon_t \\ \varepsilon_t &\sim N(0, \sigma^2). \end{aligned}$$

It is important to note at the outset that the aim of the model is *not* to replicate the moments of the main real macroeconomic aggregates; certain assumptions in the model introduced for tractability make that objective infeasible, in particular the assumption of log utility. The model performs particularly poorly with respect to real variables, as is evident in figure (2.10).[8] The aim instead is twofold: to study what features of our economy (in particular, what features related to liquidity) can bring us closer to resolving some of the main ongoing asset pricing puzzles, and secondly to analyze qualitatively how the novel features introduced in our model alter how the investment and output respond to productivity and liquidity shocks.

2.6.1 Asset Pricing Implications

Most of the existing literature on asset pricing, starting with Sharpe (1964), Lintner (1965) or Lucas (1978), is based on the role of consumers' degree of risk aversion and time preference in accounting for asset pricing regularities. A number of well documented puzzles have been raised in this literature, the most prominent of them being the equity premium puzzle (Mehra and Prescott (1985)) and the risk-free rate puzzle (Aiyagari and Gertler (1991)).[9]

Few papers in the literature have explored the asset pricing implications of production-based models. Some notable exceptions are Cochrane (1991) and (1996), who shows that such a model can fit the data better than a standard consumption-based model. His model however assumes complete markets, unlike this one, and hence does not study issues of liquidity. A more recent contribution is Jermann (2008), whose analysis is similar to Cochrane's except that his attempt is at explaining the equity premium in particular. In short, while the main focus of these papers has been on the role of technological factors in explaining asset prices, the objective of this paper is to study the role of producer-related financial frictions. Other closely related contributions in this aspect

[8] It is important not to forget that part of the source of this inability to match certain moments of real aggregate variables may be in the fact that the only source of shocks in this model are technological shocks. Their role, particularly that of negative productivity shocks, has been questioned in the literature.

[9] The equity premium and risk-free rate puzzles state that reasonably parameterized versions of the intertemporal consumption-based asset pricing model produce, respectively, too small risk premia, and too large risk-free rates.

Variable	Moment	Model 1 (Debt/GDP = 1/3)	Model 2 (Debt/GDP = 2/3)	Model 3 (Debt/GDP = 1)	Data
Risk Free Rate	Mean	-2.46%	2.07%	3.09%	1.58%
	Std Dev	(5.20%)	(12.08%)	(7.94%)	(5.33%)
Equity Return	Mean	5.83%	8.83%	9.66%	8.31%
	Std Dev	(2.04%)	(2.54%)	(2.20%)	(19.81%)
Equity Premium	Mean	8.29%	6.75%	6.58%	6.74%
	Std Dev	(0.98%)	(1.08%)	(1.09%)	
Sharpe Ratio		4.06	2.66	2.99	0.34

Table 2.1: Asset Pricing Implications of Variations in the Debt-to-GDP ratio (Source for empirical data for U.S.: Campbell (1999) and Alvarez and Jermann (2001)).

are Gomes, Yaron, and Zhang (2006) and Holmstrom and Tirole (2001). The former is an empirical study of the significance of factors related to financial constraints in explaining the cross-section of equity returns. The latter is a theoretical study that tries to bridge the gap between corporate finance and asset pricing.

Before getting into the comparative exercises, it is worth noting how both the equity premium and the risk free rate are easily matched in a production-based model such as the one presented in this paper (this can be seen in tables 2.1, 2.2 and 2.3). Additionally, it does so without having to rely on high values of entrepreneurial risk aversion (throughout all these exercises the degree of relative risk aversion is 1). Certain asset pricing regularities may remain puzzling with respect to the consumption-based literature, but not so with respect to the production-based framework.

I conduct some numerical exercises to assess the importance of three financial factors in influencing the first and second moments of the risk-free rate, the equity return, and the equity premium, as well as the Sharpe ratio. First, I study the effect of the amount of government debt as a share of GDP. In the U.S., this ratio has fluctuated between 1/3 and 1 during the post-war period, and I study the asset pricing implications of ratios of $1/3$, $2/3$ and 1. The results are on table (2.1). As expected, increases in the

Variable	Moment	Model 1 (low liquidity)	Model 2 (medium liquidity)	Model 3 (high liquidity)	Data
Risk Free Rate	Mean	-3.01%	2.07%	3.97%	1.58%
	Std Dev	(11.75%)	(11.07%)	(4.48%)	(5.33%)
Equity Return	Mean	6.51%	8.82%	10.09%	8.31%
	Std Dev	(4.15%)	(2.31%)	(1.59%)	(19.81%)
Equity Premium	Mean	9.52%	6.75%	6.12%	6.74%
	Std Dev	(1.42%)	(1.08%)	(0.97%)	
Sharpe Ratio		2.29	2.93	3.84	0.34

Table 2.2: Asset Pricing Implications of Variations in the liquidity of corporate equity (Source for empirical data for U.S.: Campbell (1999) and Alvarez and Jermann (2001)).

debt-to-GDP ratio increase the rate of return on government securities. They also raise the required rate of return on equity by depressing equity prices, which is the essence of the crowding-out effect. Empirically observed risk free rates, equity returns and equity premia are obtained for debt to equity ratios of about $2/3$. It is interesting to note how the equity premium decreases with government debt. For low values of debt-to-GDP, the premium reaches over 8%, and this can be ascribed to two factors. On the one hand, scarce government debt carries a large premium. On top of that, the negative liquidity properties of equity (its relative illiquidity and its procyclical value) become more of an issue when other sources of liquidity are scarce.

Recent empirical work has documented a decline in the U.S. equity premium. Given this result on the relationship between government debt and the equity premium, it would be interesting to study what fraction of that decrease can be accounted for by the smaller debt-to-GDP ratios seen in recent years as compared to the whole post-war period. Table 2.4 shows data on the U.S. equity premium from Jagannathan et al. (2000), which contrasted with data for public debt as a share of GDP seems to suggest a pattern of high debt ratios and low equity premia (1980s and 1990s), and vice versa (1960s and 1970s).

Variable	Moment	Model 1 (Theta Low)	Model 2 (Theta Medium)	Model 3 (Theta High)	Data
Risk Free Rate	Mean	-6.10%	2.07%	11.04%	1.58%
	Std Dev	(6.37%)	(12.08%)	(1.64%)	(5.33%)
Equity Return	Mean	3.78%	8.83%	16.01%	8.31%
	Std Dev	(7.92%)	(2.54%)	(1.19%)	(19.81%)
Equity Premium	Mean	9.87%	6.75%	4.97%	6.74%
	Std Dev	(1.31%)	(1.08%)	(0.66%)	
Sharpe Ratio		1.25	2.66	4.17	0.34

Table 2.3: Asset Pricing Implications of Variations in the pledgeability of returns (Source for empirical data for U.S.: Campbell (1999) and Alvarez and Jermann (2001)).

The second moments show some disparity with their empirical counterparts, however (this translates into Sharpe ratios which are of an order of magnitude off the empirical values). A proper investigation of this issue calls for an appropriate treatment of the source of aggregate and idiosyncratic fluctuations, which is not the object of this paper.

Turning now to the effect of the degree of liquidity of equity, ϕ, it is clear from table 2.2 that the effects on all rates of return are significant. The risk free rate varies considerably, as is expected. Relatively illiquid equity makes the economy more dependable on outside liquidity, and hence introduces a strong premium on government debt. The effect on the equity premium is also considerable. Illiquid equity carries a very high premium, as it has to compensate its holders not only for its return risk but also for its poor use as a hedge against liquidity shortages. Finally, variations in theta also have important consequences for asset pricing. A low borrowing capacity (low θ) has two implications: on the one hand, investing entrepreneurs are more liquidity constrained, and thus demand ex-ante more liquidity reserves, and on the other, the supply of inside liquidity (equity) is smaller. Both these effects cause the equity premium and the risk free rate to rise sharply the tighter the borrowing constraints are.

2.6.2 Response to Productivity and Liquidity Shocks

To explore the dynamics implied by the model we plot below the impulse responses of key macroeconomic variables to productivity and liquidity shocks in versions of the model where the level of debt-to-GDP and the degree of financial constraints are varied. The stochastic process for liquidity is assumed to be orthogonal to the productivity process to be able to identify the different results more clearly. A more in-depth study of liquidity shocks however should recognize the dependence between those shocks and productivity shocks (over and above the endogenous dependence generated between productivity and the supply of liquidity in the context of this model).

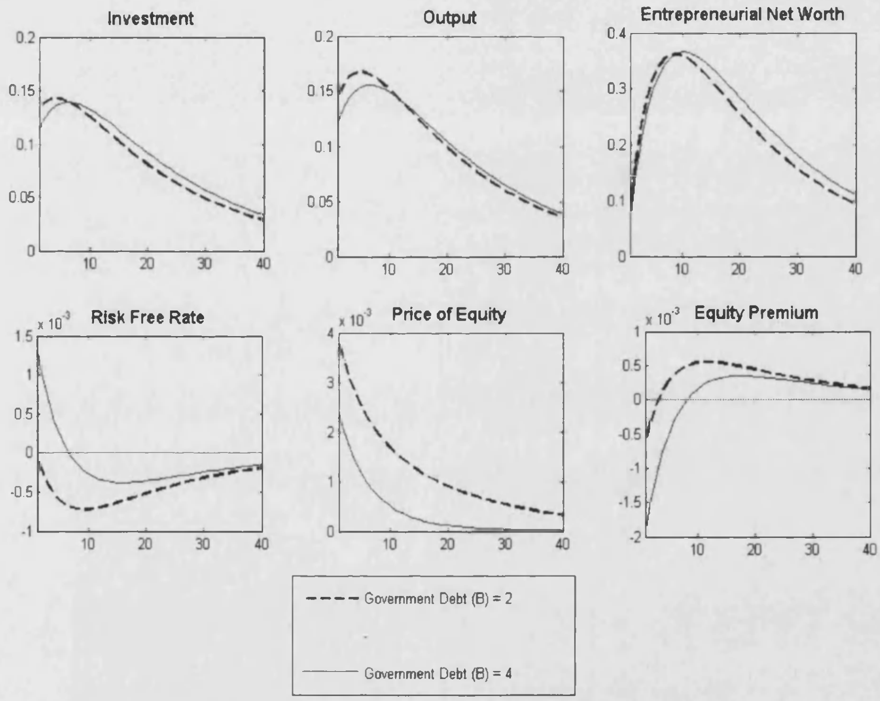

Figure 2.3: Impulse Response of Key Variables to Productivity Shock - Analysis for Different Levels of Government Debt (periods = quarters). Responses are the percentage deviation of a variable from its steady-state value.

The responses to a productivity shock are captured in figures (2.3) and (2.4), for different values of the debt-to-GDP ratio and θ. Lower values of debt-to-GDP make the response on impact of investment and output slightly higher than for higher values, although the difference is not large. Firms rely to a greater extent on equity for self-insurance, the supply of which endogenously co-moves with the cycle and acts to amplify the effect of shocks. This effect is mirrored in the financial variables. When public liquidity supply is large, the risk free rate rises sharply on impact; additional private liquidity as a result of higher equity prices on top of an already large supply of public liquidity makes saving firms require an even larger return on their holdings of government debt. But a positive productivity shock also increases the demand for liquidity from saving entrepreneurs as the expected future returns to investing increase. This second effect seems to dominate when the level of public debt is low, and the risk free rate does not increase on impact.

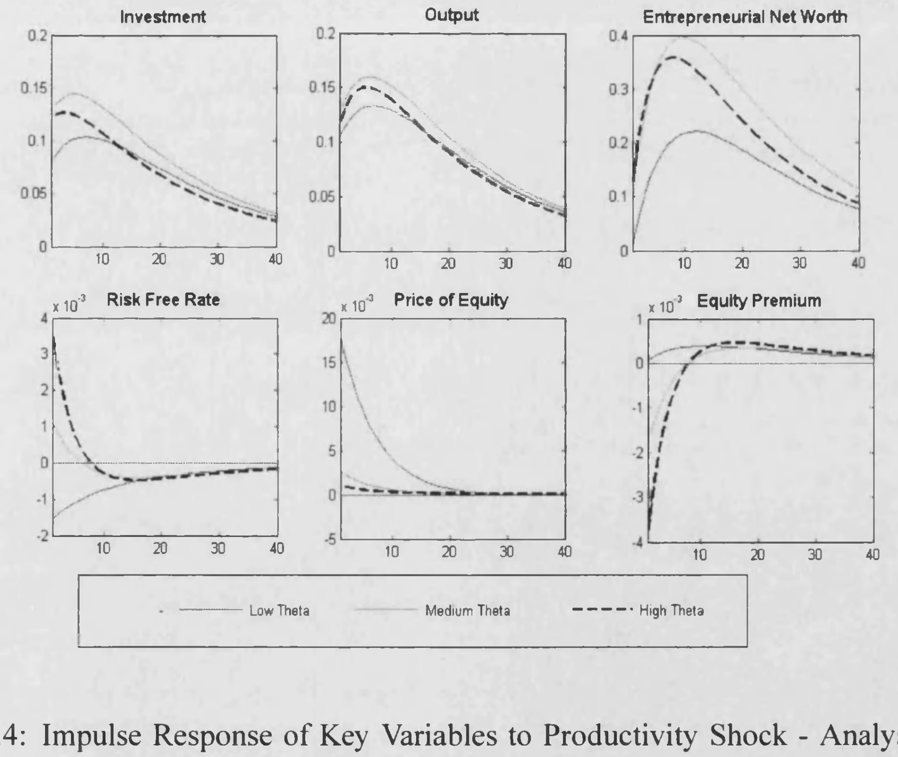

Figure 2.4: Impulse Response of Key Variables to Productivity Shock - Analysis for Different Levels of Financing Constraints (periods = quarters). Responses are the percentage deviation of a variable from its steady-state value.

With respect to the cyclical behaviour of the equity premium, empirical research has documented that risk premia are counter-cyclical (recent examples are Campbell and Cochrane (1999), Lochstoer (2006)). The consumption-based literature has tried to explain this feature through a number of ways. Constantinides and Duffie (1996) explain the countercyclicality because equity provides a bad hedge against a job loss during a recession, and hence investors require a premium during bad times for holding equity. Other papers use particular assumptions on preference characterizations that result in countercyclical coefficients of risk aversion (see Pijoan-Mas (2007)). The model introduced in this paper introduces a new explanation for the countercyclicality of the equity premium. Following a positive shock to technology, that is anticipated by agents to be persistent and to result in higher collateral values in the near future and hence less severe credit constraints, firms adjust the risk profile of their liquid portfolio to include a higher share of riskier but more profitable equities, in detriment of government liquidity. The opposite happens in downturns; firms anticipate that credit constraints have a higher probability of being tight in the near future and shift their preference towards a safer profile of their portfolio. In essence, equities provide a bad hedge against the risk of having an investment opportunity and being liquidity constrained in a downturn, and hence agents holding equities require a higher premium in downturns. This result has a similar flavour to the result on cyclical variations in the composition of investment of credit constrained firms in Perez (2008).

I also study the effect of liquidity shocks, and the results are in figure (2.5). These show that positive shocks to the liquidity of firms' equity raise investment and output to a significantly greater extent in economies with limited publicly supplied liquidity. The effect is captured as well in the reaction of the rate of return on government bonds. On impact, they rise sharply, reflecting a decrease in the liquidity premium they were previously enjoying given that the liquidity differential now between equity and government debt has been reduced.

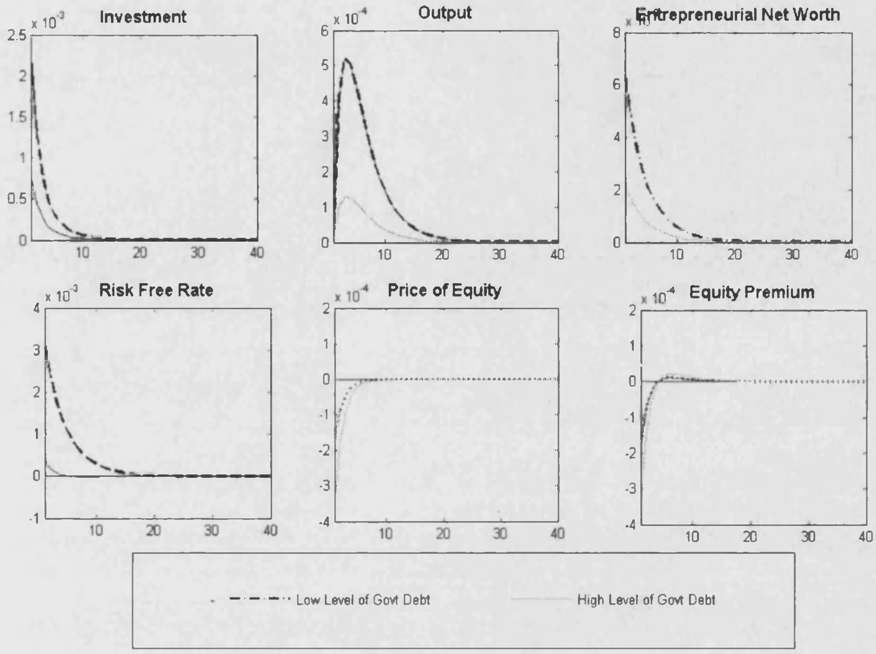

Figure 2.5: Impulse Response of Key Variables to Liquidity Shock - Analysis for Different Levels of Government Debt (periods = quarters). Responses are the percentage deviation of a variable from its steady-state value.

2.7 Conclusion

This paper has highlighted how the availability of government supplied liquidity influences the creation of private liquidity in the form of claims to the future returns of firms' investment, and the conditions under which variations in the level of government debt may affect aggregate private investment positively or negatively. This analysis, and others like it, should be taken into account when evaluating the effects of episodes such as the significant deficits of the two George W. Bush terms (2000-2004, 2004-2008). In particular, the effects identified in this paper, such as the potentially beneficial role these increased deficits may have had in supplying additional liquidity to the corporate sector, the crowding out of private investment, or the redistributive effects, have to be weighed in with other consequences of these net increases in government spending.

The results concerning the asset pricing properties of production-based models featuring financially constrained firms are promising. This framework provides interesting results in terms of matching the main empirical regularities, and in particular in terms of which elements related to liquidity are of most importance to achieving that success. Further work needs to be done in order to match the second moments of asset prices better, and as a first step, identifying better which sources of shocks matter most for asset pricing is a promising avenue.

2.A Appendix

2.A.1 Debt-to-GDP and Equity Premium data

The past decades have seen the fiscal positions of many countries improve, a trend that has been however reversed for some countries (most notable the U.S.). Below is a chart for the debt-to-GDP ratio for the U.S. for most of the post-war era. On the other hand, a strand of the empirical asset pricing literature has debated recently whether the equity premium has been secularly declining in recent times. Jagannathan et al. (2000) document significant variation in their measure of the equity premium during the past four decades, as is clear in Table 2.4.

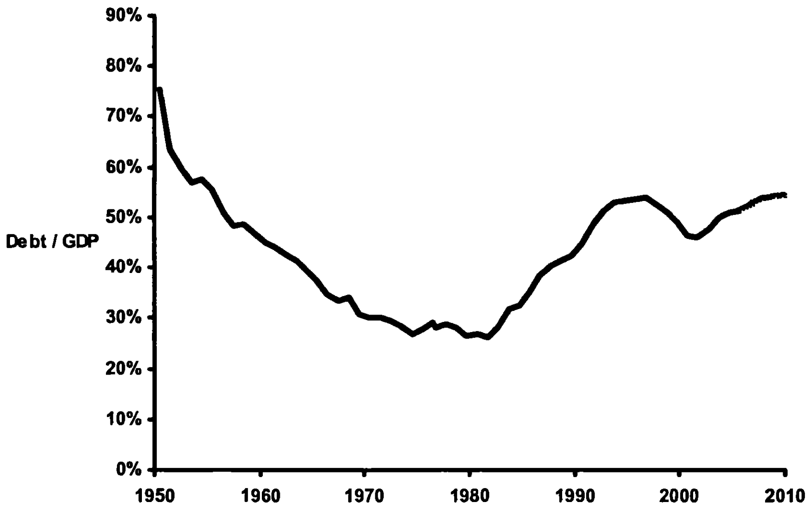

Figure 2.6: Gross National Public Debt as % of GDP for the United States. (Source: Office of Management and Budget, White House, 2008)

2.A.2 Existence and Uniqueness

The equilibrium steady state solution can be obtained by solving for K, r and q in (2.20), (2.22) and (2.23). In order to prove existence and uniqueness I make the same mild simplifying assumptions which are stated in section 2.4.1 in relation to Proposition

Period	Equity Premium	Public Debt / GDP
1960-1969	5.23%	38.9%
1970-1979	3.30%	25.6%
1980-1989	0.94%	40.0%
1990-1999	1.90%	62.9%

Table 2.4: The Equity Premium and the Gross National Public Debt as percent of GDP for the United States. (Source: Jagannathan et al. (2000) for the equity premium and Office of Management and Budget, White House, 2008)

1. Taking these into account, we can solve for K and q in (2.27) and (2.28). After rearranging, they become respectively:

$$\beta_1 K + \beta_2 K^{\alpha} + \beta_3 = 0 \tag{2.45}$$

$$\gamma_1 K + \gamma_2 K^{\alpha} + \gamma_3 qK + \gamma_4 = 0 \tag{2.46}$$

where

$$\begin{aligned}
\beta_1 &= 1 - \frac{\beta}{2}(1+\delta) \\
\beta_2 &= -\frac{\beta \alpha a}{2} \\
\beta_3 &= [(1-\beta)+1]\frac{B}{2} \\
\gamma_1 &= (1-\beta)\frac{(1-\delta)}{2}\frac{1-\phi}{1-\theta} + \delta \\
\gamma_2 &= -\frac{\beta \alpha a}{2} \\
\gamma_3 &= -\left\{\frac{(1-\delta)}{2}\left[(1-\beta)\frac{\theta}{1-\theta} + \beta\phi\right] + \theta\delta\right\} \\
\gamma_4 &= -\frac{\beta B}{2}
\end{aligned}$$

Substituting q out of (2.46) leaves us with

$$\gamma_1 K + \left(\gamma_2 - \gamma_3 \frac{\beta_2}{\beta_1}\right) K^{\alpha} + \left(\gamma_4 - \gamma_3 \frac{\beta_3}{\beta_1}\right) = 0.$$

Without loss of generality, assume $\alpha = 1/2$, make the change of variables $K = x^2$, and solve the resulting quadratic equation to get

$$\begin{aligned}
\sqrt{K} &= -\frac{1}{2\gamma_1}\left(\gamma_2 - \gamma_3 \frac{\beta_2}{\beta_1}\right) \pm \frac{1}{2\gamma_1}\sqrt{\left(\gamma_2 - \gamma_3 \frac{\beta_2}{\beta_1}\right)^2 - 4\gamma_1\left(\gamma_4 - \gamma_3 \frac{\beta_3}{\beta_1}\right)} \\
&= \frac{1}{2\gamma_1}\left[\chi_1 \pm \sqrt{\chi_1^2 + \chi_2}\right].
\end{aligned}$$

where

$$\begin{aligned}
\chi_1 &= -\left(\gamma_2 - \gamma_3 \frac{\beta_2}{\beta_1}\right), \\
\chi_2 &= -4\gamma_1\left(\gamma_4 - \gamma_3 \frac{\beta_3}{\beta_1}\right).
\end{aligned}$$

Existence

There are two possible solutions, and for there to exist at least one, it is necessary that the term inside the square root is positive, or

$$\chi_1^2 + \chi_2 \geq 0, \tag{2.47}$$

and also that at least the largest of the two solutions is positive:

$$\max\left\{\frac{1}{2\gamma_1}\left(\chi_1 + \sqrt{\chi_1^2 + \chi_2}\right), \frac{1}{2\gamma_1}\left(\chi_1 - \sqrt{\chi_1^2 + \chi_2}\right)\right\} \geq 0, \tag{2.48}$$

Given that $\gamma_1 = (1-\beta)\frac{(1-\delta)}{2}\frac{1-\phi}{1-\theta} + \delta > 0$, condition (2.48) simplifies to

$$\chi_1 + \sqrt{\chi_1^2 + \chi_2} \geq 0.$$

Condition (2.47) implies that

$$\left(\gamma_2 - \gamma_3 \frac{\beta_2}{\beta_1}\right)^2 - 4\gamma_1 \left(\gamma_4 - \gamma_3 \frac{\beta_3}{\beta_1}\right) \geq 0.$$

Uniqueness

Conditional on existence of an equilibrium, uniqueness requires that the smallest of the two solutions is strictly negative. Again, given that $\gamma_1 = (1-\beta)\frac{(1-\delta)}{2}\frac{1-\phi}{1-\theta} + \delta > 0$, uniqueness is guaranteed when:

$$\chi_1 - \sqrt{\chi_1^2 + \chi_2} < 0.$$

2.A.3 Condition for $q \geq 1$

From appendix 2.A.2 we know that:

$$K = \left[\frac{1}{2\gamma_1}\left(\chi_1 + \sqrt{\chi_1^2 + \chi_2}\right)\right]^2 \tag{2.49}$$

$$q = -\frac{\gamma_4 + \gamma_1 K + \gamma_2 K^\alpha}{\gamma_3 K}. \tag{2.50}$$

From (2.50) we can obtain the parameter restriction that ensures that $q \geq 1$ in the neighbourhood of the steady state when all taxes are levied on workers, and $\alpha = 1/2$.

2.A.4 Proof of Proposition 1

Once again, we focus on the case in which we abstract from the *inter-sectorial redistributive effect* by levying all taxes on the entrepreneurial sector.

In appendix (2.A.2) we show that the unique steady state solution to the equilibrium conditions is

$$K = \left[\frac{1}{2\gamma_1}\left(\chi_1 + \sqrt{\chi_1^2 + \chi_2}\right)\right]^2.$$

where

$$\begin{aligned}\chi_1 &= -\left(\gamma_2 - \gamma_3\frac{\beta_2}{\beta_1}\right),\\ \chi_2 &= -4\gamma_1\left(\gamma_4 - \gamma_3\frac{\beta_3}{\beta_1}\right).\end{aligned}$$

We want to analyze how the steady state level of capital varies with the amount of government debt, or

$$sign\left(\frac{dK}{dB}\right) = sign\left\{\frac{d\left\{\left[\frac{1}{2\gamma_1}\left(\chi_1 + \sqrt{\chi_1^2 + \chi_2}\right)\right]^2\right\}}{dB}\right\}. \tag{2.51}$$

Given that

$$\frac{d\chi_1}{dB} = 0,$$

and that χ_2 is a linear function of B, then we can simplify (2.51) to

$$sign\left(\frac{dK}{dB}\right) = sign\left\{\chi_2\right\}, \tag{2.52}$$

where

$$\chi_2 = 4\gamma_1\left(-\gamma_4 + \gamma_3\frac{\beta_3}{\beta_1}\right).$$

Given that $\gamma_1 = (1-\beta)\frac{(1-\delta)}{2}\frac{1-\phi}{1-\theta} + \delta > 0$, and $\beta_1 = 1 - \frac{\beta}{2}(1-\delta) > 0$, then

$$sign\left(\frac{dK}{dB}\right) = sign\left\{-\beta_1\gamma_4 + \gamma_3\beta_3\right\} \tag{2.53}$$

where

$$
\begin{aligned}
-\beta_1\gamma_4 + \gamma_3\beta_3 = \beta\left[1 - \frac{\beta}{2}(1-\delta)\right] \\
- \left\{\frac{(1-\delta)}{2}\left[(1-\beta)\frac{\theta}{1-\theta} + \beta\phi\right] + \theta\delta\right\}[(1-\beta)+1]. \qquad (2.54)
\end{aligned}
$$

The first term in the right-hand side of (2.54) is always positive and is not a function of either θ or ϕ, while the second term is always negative and is a negative function of both θ or ϕ. Remembering that $0 \leq \theta \leq 1$ and $0 \leq \phi \leq 1$, for $\theta = \phi = 0$, $dK/dB > 0$ and the crowding-in effect dominates. For $\theta = 1$ and $0 \leq \phi \leq 1$, $dK/dB = -\infty$ and the crowding-out effect dominates. Call θ^* the level at which both effects balance out when $\phi = 0$. For $\phi = 1$ and $\theta = 0$, $sign(dK/dB) = sign\{\delta\} > 0$, but there exists θ^{**} that satisfies $0 < \theta^{**} < \theta^*$ such that for $\phi = 1$ and $\theta > \theta^{**}$, $sign(dK/dB) < 0$.

2.A.5 Steady State Numerical Exercises

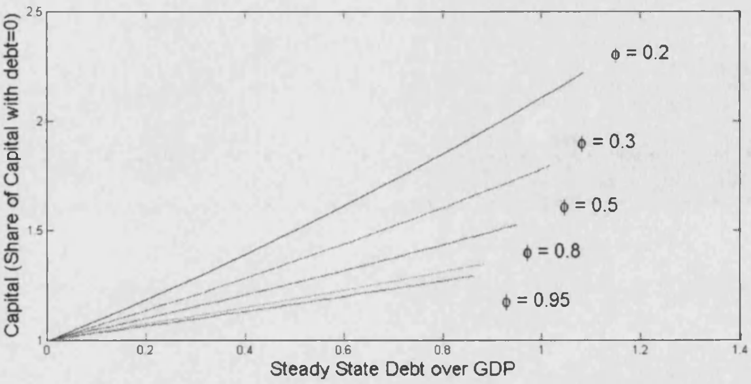

Figure 2.7: Effect of Variations in the Ratio of Debt to GDP on the Level of Capital, for Different Levels of Financial Constraints, when all Taxes are Paid for by Saving Entrepreneurs (i.e. when not taking into account the inter-sectorial distributive effects).

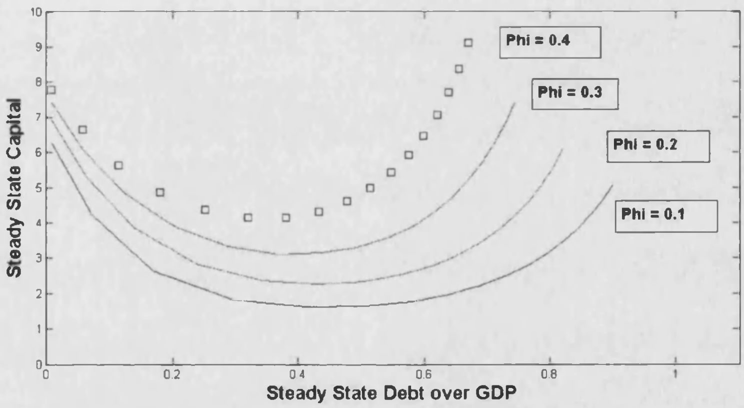

Figure 2.8: Effect of Variations in the Ratio of Debt to GDP on the Level of Capital, for Different Levels of Liquidity, when all Taxes are Paid for by Workers (i.e. when taking into account the inter-sectorial distributive effects).

2.A.6 Computational Procedure for Section 5 - Dynamics

The dynamic model is solved by performing a quadratic approximation of the decision rules using a perturbation approach as in Schmitt-Grohe and Uribe (2004). Below are the policy and transition functions in the baseline calibration.

	Investment	Net Worth	RiskFree Rat	Equity Premium	Output	Equity Re
Constant	9.7763	31.1214	0.5172	-0.5172	11.4172	0.6767
k (-1)	0.0789	0.7361	-0.0069	0.0072	0.1752	-0.0009
z (-1)	11.4234	11.3092	0.3377	-0.3593	10.8463	0.0930
e	12.0247	11.9044	0.3555	-0.3782	11.4172	0.0979
k (-1),k (-1)	-0.0012	-0.0012	0.0001	-0.0001	-0.0013	0.0000
z (-1),k (-1)	0.1742	0.1724	-0.0028	0.0027	0.1664	0.0002
z (-1),z (-1)	-0.7817	-0.7739	-0.0431	0.0589	-0.2712	-0.0692
e,e	5.4627	5.4080	0.1393	-0.1337	5.7086	-0.0252
k (-1),e	0.1833	0.1815	-0.0030	0.0028	0.1752	0.0002
z (-1),e	10.3790	10.2753	0.2647	-0.2541	10.8463	-0.0479

Figure 2.9: Policy and Transition Functions in Baseline Calibration

	Model		Data	
Variable	Standard Deviation (as %)	Std Dev / Std Dev Output	Standard Deviation (as %)	Std Dev / Std Dev Output
Consumption	1.68	0.79	0.82	0.38
Investment	3.41	1.60	8.07	3.79
Real wage	2.17	1.02	0.89	0.42
Output	2.12	1.00	2.13	1.00

Figure 2.10: Moments of Real Macroeconomic Variables in the Data and in the Baseline Calibration of the Model. (Data from Uhlig (2006)).

Chapter 3

Financial Innovation, Macroeconomic Stability and Systemic Crises

3.1 Introduction

> *"When [financial] innovation ... takes place in a period of generally favorable economic and financial conditions, we are necessarily left with more uncertainty about how exposures will evolve and markets will function in less favorable circumstances. The past several years of exceptionally rapid growth in credit derivatives and the larger role played by nonbank financial institutions, including hedge funds, has occurred in a context of ... relatively strong and significantly more stable economic growth, less concern about the level and volatility in future inflation, and low expected volatility in many asset prices. Even if a substantial part of these changes prove durable, we know less about how these markets will function in conditions of stress..."* (Geithner, 2006)

Systemic financial crises often occur when investment booms and rapid credit expansions collapse because the expectations of high future returns that drove them are not fulfilled (Borio and Lowe, 2002; Eichengreen and Mitchener, 2003). But while investment booms and busts have been an important part of recent financial crises in emerging market economies, their impact on financial stability in the advanced economies has been less marked. Greater macroeconomic stability and the growing sophistication of financial intermediation appear to have reduced the incidence of crisis. Increasingly, however, policymakers have become concerned that while these factors may have helped to reduce the likelihood of systemic crises, their impact, should one occur, could be on a significantly larger scale than hitherto (see, for example, Rajan, 2005, Tucker, 2005, and Gieve, 2006).[1]

It is difficult to make judgments on such issues without formally modelling the underlying externalities associated with systemic financial crises. One strand of the literature (e.g. Aghion *et al.*, 1999; Aghion *et al.*, 2001) draws on Kiyotaki and Moore (1997) to highlight credit frictions arising from enforcement problems.[2] These papers illustrate how endogenous balance sheet constraints, and financial development more generally, contribute to financial instability. But since these papers do not permit state-contingent financial contracts, the extent to which the underlying externality drives their results is unclear. By contrast, in existing models with state-contingent contracts (e.g. Kehoe and Levine, 1993; Krishnamurthy, 2003; Lorenzoni, 2005; Gai *et al.*, 2006), investment projects are never abandoned and crises never occur. Moreover, these papers do not consider the effects of financial innovation or changes in macroeconomic volatility.

This paper seeks to bridge this gap. We develop a general equilibrium model of intermediation with financial constraints and state-contingent contracts. Systemic financial crises are generated through a clearly defined pecuniary externality associated with asset 'fire sales' during periods of stress. Moreover, the potential for instability is

[1] Gai *et al.* (2007) discuss the implications of these issues for risk assessment work at the Bank of England.

[2] An alternative strand of the literature highlights coordination problems amongst financial market participants as the key externality driving financial crises. See, for example, Diamond and Dybvig (1983), Obstfeld (1996), and Morris and Shin (1998).

present *ex ante* and does not rely on sunspots or other undefined factors external to the model.

In our setup, consumers channel funds through collateral-constrained financial intermediaries to firms operating in more-productive sectors of the economy. Firms manage investment projects but intermediaries retain financial control over them. Even though financial contracts can be made contingent on the aggregate state, enforcement problems mean that insurance opportunities for intermediaries are limited. As a result, adverse aggregate shocks to the productive sectors of the economy may force intermediaries to sell capital to less-productive sectors to remain solvent. In the spirit of Fisher (1933) and Shleifer and Vishny (1992), this distress selling is associated with reduced asset prices.[3] In turn, this creates a feedback to net worth which affects the balance sheets of all intermediaries, potentially leading to further asset sales. Since intermediaries do not internalise the effect on asset prices of their own sales, the competitive equilibrium is constrained inefficient. In extreme cases, it is this externality which can result in a systemic financial crisis that may be self-fulfilling.

The analysis points to a range of possible outcomes. Since expected future returns in productive sectors are high, initial investment is always strong and associated with a large credit expansion. Provided that there is *no adverse shock*, investment and credit growth remain robust, and there are no asset sales. For *mild negative shocks*, firms and intermediaries liquidate some of their assets. However, since intermediaries remain solvent and firms continue to operate in productive sectors, this outcome can be viewed as a 'recession' rather than a systemic crisis.

For *more severe shocks*, multiple equilibria can arise, with (*ex ante*) beliefs determining the actual equilibrium which results. Multiplicity can occur in bad states because the supply of capital by intermediaries during fire sales is downward sloping in

[3] In a study of commercial aircraft transactions, Pulvino (1998) finds evidence for this type of fire sale effect; Coval and Stafford's (2007) analysis of mutual fund asset sales demonstrates that these effects may be present even in highly liquid markets.

price, since the lower the price, the more capital they will have to sell to remain solvent. If agents have 'optimistic' beliefs about how the economy will evolve under stress, there will only be a partial liquidation of assets, as in the 'recession' case. But if beliefs are 'pessimistic', a systemic financial crisis occurs. Moreover, for *extremely severe shocks*, a crisis is inevitable, regardless of beliefs. Under this scenario, asset prices are driven down to such an extent that all intermediaries and firms are forced to liquidate all of their assets – a full-blown financial crisis occurs, intermediaries shut down, and the closure of firms means that there are no investment opportunities in the more-productive sectors of the economy.

The financial system has been changing rapidly in recent years. Intermediation is increasingly conducted through non-bank intermediaries such as private equity firms and hedge funds, who typically have higher leverage in risk-adjusted terms than traditional banks. Resale markets for capital have deepened, and sophisticated financial products and contracts, such as credit derivatives and asset-backed securities, have mushroomed (White, 2004; Allen and Gale, 2007; Plantin *et al.*, 2007). Our model suggests that these developments may have made economies less vulnerable to crises as they widen access to liquidity and allow assets to be traded more easily during periods of stress. But, by relaxing financial constraints facing borrowers, they imply that, should a crisis occur, its impact could be more severe than previously.

We demonstrate how these effects may be reinforced by greater macroeconomic stability.[4] Our model predicts that mean preserving reductions in volatility make crises less likely since severe shocks occur less frequently. However, greater stability also makes 'recession' states less likely. As a result, consumers are more willing to lend, allowing intermediaries to increase their borrowing and initial investment. But, if a crisis does then ensue, losses will be greater. Overall, our findings thus make clear how financial innovation and increased macroeconomic stability may serve to reduce

[4]A range of empirical studies (e.g. Benati, 2004; Stock and Watson, 2005) find that output and inflation volatility have fallen in many developed countries in recent years.

the likelihood of crises in developed countries, but increase their potential impact.

Our paper has several points of contact with the literature. The model has some similarities to Holmstrom and Tirole (1998) and Jermann and Quadrini (2006), and builds on Lorenzoni's (2005) analysis of lending under endogenous financial constraints and asset prices. It differs in two key respects. First, we show how multiple equilibria and systemic crises can arise in such a model. Second, we capture some of the key features of intermediation in the modern financial system: though our model also applies to traditional banks, it is especially relevant to the activities of hedge funds, private equity firms, and other non-bank financial institutions. These developments allow us to model the effects of financial innovation and greater macroeconomic stability on the likelihood and potential scale of systemic crises.

In recent work, Allen and Carletti (2006) also assess the systemic effects of financial innovation. But they have a specific focus on credit risk transfer between banks and insurance companies, and on how its effects differ according to the type of liquidity risk that banks face. In particular, their model highlights how, in some circumstances, credit risk transfer can create the potential for contagion from the insurance sector to the banking sector, and thus be detrimental. By contrast, we consider the more general consequences of financial innovation through its broader impact on financial constraints and the depth of resale markets.[5]

The rest of the paper is structured as follows. Section 3.2 presents the basic structure of the model, while section 3.3 solves for equilibrium and discusses how multiplicity and systemic financial crises arise. Section 3.4 considers the effects of financial innovation and changes in macroeconomic volatility on the likelihood and potential scale of financial crises. A final section concludes.

[5]Financial innovation may also increase uncertainty about the behaviour of financial markets. We leave this issue aside and just focus on capturing the effects of certain trends linked to financial innovation.

3.2 The Model

The economy evolves over three periods ($t = 0, 1, 2$) and has two goods, a consumption good and a capital good. Consumption goods can always be transformed one for one into capital goods, but not vice versa. Because of the irreversibility of investment, the price of the capital good in terms of the consumption good (the asset price), q, may be less than one in the event of asset sales – this is one of the key drivers of our results.

3.2.1 Financial Intermediaries and Other Agents

The economy is composed of consumers, financial intermediaries, and firms, with large numbers of each type of agent. All agents are risk-neutral and identical within their grouping, and there is no discounting.

Consumers aim to maximise total consumption, $c_0 + c_1 + c_2$, where c_t is consumption in period t. They each receive a large endowment, e, of the consumption good in every period. Since they are only able to produce using a relatively unproductive technology operating in the traditional sector of the economy, they channel funds through intermediaries to firms operating in the more-productive sector of the economy.[6]

Intermediaries in the model are best viewed as operating in the modern financial system: they could be interpreted as traditional banks, but our model is also designed to apply to the activities of hedge funds, private equity firms, and other non-bank financial institutions. They borrow from consumers and invest in firms in order to maximise total profits, $\pi_0 + \pi_1 + \pi_2$, where profits and consumption goods are assumed to be

[6] Although intermediaries clearly have an important role in practice, there is nothing in the structure of our model which precludes consumers from investing directly in firms. We could formally motivate the existence of intermediaries by, for example, introducing asymmetric information or, more specifically, following Diamond and Dybvig (1983) or Holmstrom and Tirole (1998). But this would significantly complicate the analysis without changing our main results. Therefore, for simplicity and transparency, we simply assume that consumers can only invest in the more-productive sector through intermediaries. Indeed, the involvement of intermediaries in investment projects in the more-productive sector could be interpreted as partially driving the higher returns in that sector relative to the traditional sector.

interchangeable. However, their wealth is relatively limited: although they receive an endowment, n_0, of the consumption good in period 0 (this may be thought of as their initial net worth), this is assumed to be very small relative to e. We also assume that intermediaries are unable to trade each other's equity due to limited commitment, though relaxing this assumption does not affect our qualitative results.

Firms have no special role in our setup. They are agents with no net worth who manage investment projects in exchange for a negligible payment – this could be viewed as following from perfect competition amongst firms. Since this implies that intermediaries effectively have complete control over investment projects, we abstract from the behaviour of firms in all of what follows, and simply view intermediaries as having direct access to the productive technology.

The assumption that intermediaries have financial control over firms may appear somewhat extreme. But it embeds some of the recent developments in financial markets in a simple way. In particular, as Plantin *et al.* (2007) stress, the greater use of sophisticated financial products such as credit derivatives, and the deepening of resale markets for capital have made it easier for intermediaries to trade their assets (i.e. their loans / investments in firms). This especially applies to non-traditional financial intermediaries.

3.2.2 Production Opportunities

Figure 3.1 depicts the timing of events. Intermediaries can invest in the productive sector in periods 0 and 1. Since there is no depreciation, an investment of i_0 in period 0 delivers i_0 units of capital in period 1. We also suppose it delivers xi_0 units of the consumption good (profit) in period 1, where x is a common aggregate shock with distribution function $H(x)$. The realisation of x is revealed to all agents in period 1, depends on the aggregate state, s, and can be contracted upon. Intuitively, the shock represents the per unit surplus (positive x) or shortfall (negative x) in period 1 revenue relative to (future) operating expenses. Alternatively, a positive x could be viewed as an early return on investment and a negative x as a restructuring cost or an additional capital cost which must be paid to continue with the project. Under both interpretations, a negative x does not need to be paid by anyone if the investment project is abandoned. But, when analysing the welfare gains associated with the social planner's solution, we allow for the possibility that an unpaid negative x imposes a cost to society of $w = -\lambda x$, where $0 < \lambda < 1$.

Let $E(x) = \mu > 0$, so that early investment in period 0 is expected to be profitable. If x turns out to be negative, the intermediary has two options: it can either incur the cost xi_0 (possibly by selling a portion of its capital to consumers) and continue with the investment project; or it can go into liquidation, abandoning the project and selling all of its capital to consumers.[7] In the latter case, it receives zero profit in period 2 but does not need to pay xi_0. In what follows, we associate total liquidation by the representative intermediary as reflecting a systemic financial crisis.[8]

In period 1, intermediaries can either sell k^S units of capital to consumers or make an additional investment, $i_1 \geq 0$. Therefore, they enter period 2 owning a total capital stock of:

$$k_s = i_0 - k_s^S + i_{1s}. \tag{3.1}$$

Invested in the productive sector, this capital yields Ak_s units of the consumption good in period 2, where A is a constant greater than one.

If consumers acquire capital from intermediaries in period 1, they can also use it to produce consumption goods in period 2, but they only have access to a less-productive technology operating in the perfectly competitive traditional sector of the economy. In

[7] Since intermediaries are homogeneous and unable to trade each other's equity, there is no scope for them to sell capital to each other following a negative aggregate shock.

[8] As financial contracts are fully state-contingent in this model (see section 3.2.3), they will be specified so that repayments from intermediaries to consumers are zero in states in which intermediaries are solvent but in severe distress. Since this implies that intermediaries never default on their contractual liabilities to consumers, it makes sense to associate systemic financial crises with total liquidation.

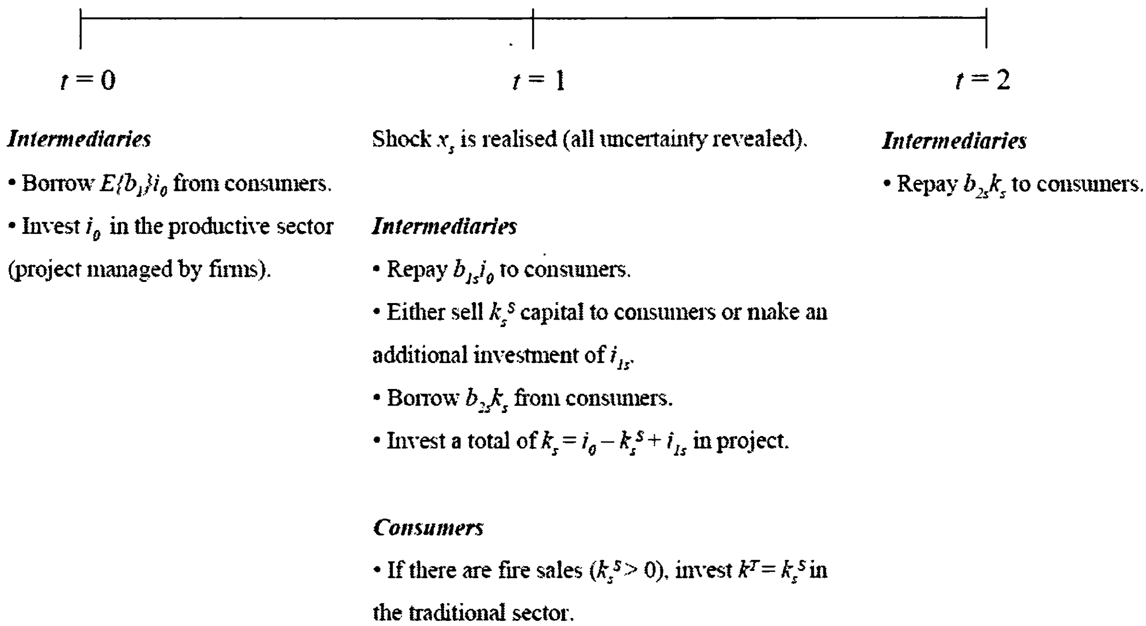

Figure 3.1: Timeline of Events

particular, the production function in the traditional sector, $F\left(k^T\right)$, displays decreasing returns to scale, with $F'\left(k^T\right) > 0$ and $F''\left(k^T\right) < 0$. For simplicity, $F'(0) = 1$, implying that there is no production in the traditional sector unless $q < 1$ (i.e. unless intermediaries sell capital in period 1). To aid intuition, we assume the specific form:

$$F\left(k^T\right) = k^T\left(1 - \alpha k^T\right), \tag{3.2}$$

where $2\alpha k^T < 1$. We also assume that capital used in the traditional sector depreciates fully after one period, so that it is worthless in period 2.

The diminishing returns embedded in the production function are designed to capture the link, highlighted by Shleifer and Vishny (1992), between distress selling of capital and reduced asset prices. As they argue, many physical assets (e.g. oil tankers, aircraft, copper mines, laboratory equipment etc.) are not easily redeployable, and the portfolios of intermediaries, many of which contain exotic tailor-made assets, are similar in this regard. Therefore, if an aggregate shock hits an entire sector, participants in that sector wishing to sell assets may be forced to do so at a substantial discount to industry outsiders.

The parameter α reflects the productivity of second-hand capital. Although this partly depends on the underlying productivity of capital in alternative sectors, it also captures the effectiveness with which capital is channelled into its most effective use when it is sold. As such, it is likely to be decreasing in financial market depth (note that $\alpha = 0$ corresponds to constant returns to scale in the traditional sector). Since increased market participation, greater global mobility of capital, and the development of sophisticated financial products may all serve to deepen resale markets, α is likely to have fallen in recent years.

3.2.3 Financial Contracts and Constraints

Intermediaries partially finance investment projects by borrowing. At date 0, they offer a state-contingent financial contract to consumers. As shown in the timeline, this specifies repayments in state s of $b_{1s}i_0$ in period 1 and $b_{2s}k_s$ in period 2, and borrowing of $E(b_1)\,i_0$ in period 0 and $b_{2s}k_s$ in period 1 and state s, where b is the repayment / borrowing ratio. Since period 1 repayments to consumers on period 0 lending are state-contingent, this has some features of an equity contract. In particular, the contract is capable of providing intermediaries with some insurance against aggregate shocks.

Although this contract is fully contingent on the aggregate state, it is subject to limited commitment and potential default. This friction is fundamental to the model: without it, the competitive equilibrium would be efficient and systemic financial crises would never occur. Its significance lies in the borrowing constraints which it imposes on financial contracts:

$$(b_{1s}i_0 - b_{2s}k_s) + b_{2s}k_s \geq 0 \qquad \forall s, \tag{3.3}$$

$$b_{2s}k_s \geq 0 \qquad \forall s, \qquad (3.4)$$

$$b_{1s}i_0 \leq \theta q_{1s}i_0 \qquad \forall s, \qquad (3.5)$$

$$b_{2s}k_s \leq \theta q_{2s}k_s \qquad \forall s, \qquad (3.6)$$

where q_{ts} is the asset price in period t and state s, and $\theta \leq 1$ is the fraction of the asset value that can be used as collateral.

The first two constraints, (3.3) and (3.4), reflect limited commitment on the consumer side. In particular, they imply that net future repayments to consumers must be non-negative. In other words, regardless of the state, consumers cannot commit to make net positive transfers to intermediaries at future dates. Constraint (3.3) relates to net future repayments as viewed in period 0 (for which additional intermediary borrowing in period 1 must be taken into account); constraint (3.4) relates to future repayments as viewed in period 1. These constraints follow from assuming that the future income of consumers cannot be seized – consumers can always default on their financial obligations.[9]

The final two constraints, (3.5) and (3.6), specify that intermediaries can only borrow up to a fraction, θ, of the value of their assets in each period, where we define θ to be the maximum loan-to-value ratio. Jermann and Quadrini (2006, Appendix B) present a simple model which motivates constraints such as these. In particular, they link an equivalent parameter to θ to the value of capital recovered upon default relative to its original value when held by the borrower, and to the relative bargaining power of borrowers and lenders. Importantly, if the recovery rate is less than one, the maximum loan-to-value ratio will also be less than one. As argued by Gai *et al.* (2006), recovery rates below one may reflect transaction costs built into the specifics of collat-

[9]Collectively, it would be in the interests of consumers to commit to make net positive transfers to intermediaries in certain states at future dates. But such a commitment is not incentive compatible since consumers each have an individual incentive to renege *ex post*. Limited commitment on the consumer side can thus also be viewed as stemming from the lack of a suitable commitment device amongst consumers.

eral arrangements, such as dispute resolution procedures. Alternatively, there may be human capital loss associated with default.

We regard the maximum loan-to-value ratio as being linked to the level of financial market development. It seems likely that financial innovation may have increased θ in recent years. Deeper resale markets may have reduced the human capital loss associated with default, and could have enabled sellers of assets seized upon default to pass on a larger proportion of the resale transaction costs to buyers than previously.[10] More generally, the greater use of credit derivative and syndicated loan markets may have increased recovery rates for lenders. Alternatively, as highlighted by Jermann and Quadrini (2006), the development of more sophisticated asset-backed securities may have made it easier for borrowers to pledge their assets as collateral to lenders. All of these factors may have made investors willing to accept higher loan-to-value ratios, thus raising θ.

It is clear that some of these factors relate to the depth of secondary markets. As such, increases in θ may be closely tied to reductions in α. This concurs with broader theoretical arguments linking the debt capacity of investors to the liquidity and depth of the secondary markets for assets used as collateral for that debt. For example, Williamson (1988) and Shleifer and Vishny (1992) discuss how the redeployability of assets is a key factor in determining their liquidation value and that this, in turn, affects investors' debt capacity. More recently, Brunnermeier and Pedersen (2006) have studied the relationship between the leverage capacity of traders and financial market liquidity, demonstrating that they are likely to be positively correlated and, importantly, that causality can run both ways.

[10]The latter point could potentially be modelled formally in a Nash bargaining framework – for a related model in this spirit, see Duffie *et al.* (2005).

3.3 Equilibrium

We now solve for equilibrium, focusing primarily on the competitive outcome. Since consumers expect investment in the productive sector of the economy to be profitable, and since they have very large endowments relative to financial intermediaries, they always meet the borrowing demands of intermediaries provided that constraints (3.3)-(3.6) are satisfied. Meanwhile, as noted above, firms simply manage investment projects for a negligible wage. Therefore, we can solve for the competitive equilibrium by considering the optimisation problem of the representative intermediary.

3.3.1 The Representative Intermediary's Optimisation Problem

The representative intermediary's optimisation problem is given by:

$$\max_{\pi_0,\{\pi_{1s}\},i_0,\{k_s\},\{b_{1s}\},\{b_{2s}\}} E_0\left(\pi_0+\pi_1+\pi_2\right)$$

subject to:

$$\pi_0 + q_0 i_0 = n_0 + E\left(b_1\right) i_0, \tag{3.7}$$

$$\pi_{1s} + q_{1s}k_s = q_{1s}i_0 + x_s i_0 - b_{1s}i_0 + b_{2s}k_s \quad \forall s\text{: partial or no liquidation,} \tag{3.8}$$

$$\pi_{1s} = q_{1s}i_0 - b_{1s}i_0 \quad \forall s\text{: total liquidation in period 1,} \tag{8L}$$

$$\pi_{2s} = Ak_s - b_{2s}k_s \quad \forall s\text{: partial or no liquidation,} \tag{3.9}$$

$$\pi_{2s} = 0 \quad \forall s\text{: total liquidation in period 1,} \tag{9L}$$

$$0 \le b_{1s} \le \theta q_{1s} \quad \forall s, \tag{3.10}$$

$$0 \le b_{2s} \le \theta q_{2s} \quad \forall s. \tag{3.11}$$

Equation (3.7) represents the intermediary's period 0 budget constraint: investment costs and any profits taken by the intermediary in period 0 must be financed by its endowment (initial net worth) and borrowing from consumers.[11] In period 1, provided that the investment project is continued (i.e. provided that the intermediary does not go into total liquidation), the intermediary's budget constraint is given by (3.8): financing is provided by start of period assets at their market value ($q_{1s}i_0$) and net period 1 borrowing ($b_{2s}k_s - b_{1s}i_0$), adjusted for the revenue surplus or shortfall, $x_s i_0$. Period 2 profits in this case are then given by (3.9). By contrast, if the intermediary goes into total liquidation in period 1, it sells all of its capital at the market price, yielding $q_{1s}i_0$ in revenue. Therefore, its period 1 profits are given by (8L), while period 2 profits are zero (equation (9L)). Finally, note that (3.10) and (3.11) simply represent combined and simplified versions of the borrowing constraints, (3.3)-(3.6).

This optimisation problem can immediately be simplified. Since expected returns on investment are always high, it is clear that the intermediary will never take any profits until period 2 unless it goes into total liquidation.[12] Therefore $\pi_0 = 0$ in (3.7) and $\pi_{1s} = 0$ for all s in (3.8). Moreover, given that the high return between periods 1 and 2 is certain, intermediaries wish to borrow as much as possible in period 1. So (3.11) binds at its upper bound and $b_{2s} = \theta q_{2s}$. Finally, the asset price is only endogenous in period 1: $q_0 = 1$ because of the large supply of consumption goods in period 0 and we set $q_{2s} = 1$ for all s.[13] Therefore, we can rewrite the intermediary's optimisation

[11] Both this and the other budget constraints must bind by local non-satiation.

[12] Period 1 profits may be positive if the intermediary goes into total liquidation because it does not need to pay xi_0 if it shuts down and can retain any proceeds remaining from asset sales after outstanding liabilities have been paid. Note that total profits are still increasing in x; the only difference is that if the intermediary continues to operate, it takes its (higher) profits in period 2 and nothing in period 1.

[13] We set $q_{2s} = 1$ because we wish to allow for borrowing between periods 1 and 2 without setting up an infinite horizon model. This assumption can be justified by assuming that period 2 returns are realised in two stages. In the first stage, the intermediaries must control the capital and $(A-1)k_s$ units of the consumption good are realised; in the second stage, k_s units are realised irrespective of who controls the capital. Between these stages, intermediaries must repay consumers with consumption goods and, if necessary, a portion of their capital – if they do not, their capital will be seized. Since everyone can gain a return from capital at this point, its marginal value is one, and hence $q_{2s} = 1$.

problem as:

$$\max_{i_0,\{k_s\},\{b_{1s}\}} E_0 (\pi_1 + \pi_2)$$

subject to:

$$i_0 = n_0 + E(b_1)\, i_0, \tag{3.12}$$

$$q_{1s}k_s = q_{1s}i_0 + x_s i_0 - b_{1s}i_0 + \theta k_s \qquad \forall s\text{: partial or no liquidation,} \tag{3.13}$$

$$\pi_{1s} = q_{1s}i_0 - b_{1s}i_0 \qquad \forall s\text{: total liquidation in period 1,} \tag{8L}$$

$$\pi_{2s} = Ak_s - \theta k_s \qquad \forall s\text{: partial or no liquidation,} \tag{3.14}$$

$$\pi_{2s} = 0 \qquad \forall s\text{: total liquidation in period 1,} \tag{9L}$$

$$0 \leq b_{1s} \leq \theta q_{1s} \qquad \forall s. \tag{3.10}$$

3.3.2 Multiple Equilibria and Systemic Crises: Intuition

Before solving the intermediary's optimisation problem, we graphically illustrate how multiple equilibria and systemic financial crises arise in the model. Faced with a negative realisation of x, intermediaries may be forced to sell a portion of their capital to the traditional sector in period 1 to remain solvent. In these fire sale states, $i_{1s} = 0$ and, using (3.1), $k_s = i_0 - k_s^S = i_0 - k_s^T$, where $k_s^S = k_s^T \leq i_0$. Provided that intermediaries remain solvent, we can substitute this expression into (3.13) and rearrange to obtain the inverse supply function for capital in the traditional sector:

$$q_{1s} = \frac{(b_{1s} - x_s - \theta)\, i_0}{k_s^T} + \theta. \tag{3.15}$$

From (3.15), it is clear that the supply function is downward sloping and convex. The intuition for this is that when the asset price falls, intermediaries are forced to sell more capital to the traditional sector to remain solvent; the more the asset price falls, the more capital needs to be sold to raise a given amount of liquidity. Equation (3.15) holds for all $k_s^T < i_0$. But if intermediaries sell all of their capital and go into liquidation, the supply of capital to the traditional sector is simply given by:

$$\left(k_s^T\right)^L = i_0. \tag{3.16}$$

Meanwhile, since the traditional sector is perfectly competitive, the inverse demand function for capital sold by intermediaries follows directly from (3.2):

$$q = F'\left(k^T\right) = 1 - 2\alpha k^T. \tag{3.17}$$

This function is downward sloping and linear due to linearly decreasing returns to scale in the traditional sector. Combining (3.15), (3.16) and (3.17) yields the equilibrium asset price(s) in fire sale states.

The supply and demand functions are sketched in $\left(q, k^T\right)$ space in Figure 3.2. As can be seen, there is the potential for multiple equilibria in fire sale states. In particular, if the supply schedule is given by S'', there are three equilibria: R$''$, U and C. From (3.15), $S(0) > 1$ for all supply schedules. Therefore, U is unstable but the other two equilibria are stable. Point C corresponds to a crisis: intermediaries go into liquidation, firms shut down, and all capital is sold to the traditional sector, causing the asset price to fall substantially. By contrast, at R$''$, fire sales are limited and the asset price only falls slightly – we view this as a 'recession' equilibrium since intermediaries remain solvent and firms continue to operate in the productive sector.

The actual outcome between R$''$ and C is determined solely by beliefs: if intermediaries believe *ex ante* (before the realisation of the shock) that there will be a systemic crisis in states for which there are multiple equilibria, a crisis will indeed ensue in those states; if they believe *ex ante* that there will only be a 'recession' in those states, then that will be the outcome. Moreover, their *ex ante* investment and borrowing decisions depend on their beliefs. Therefore, multiple equilibria arise *ex ante*: after beliefs have

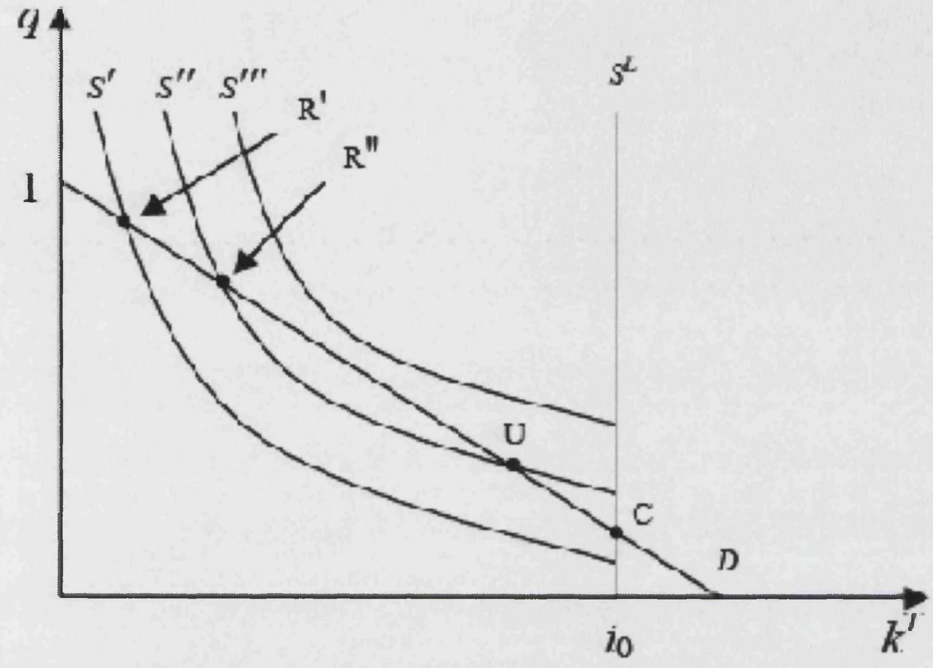

Figure 3.2: Demand and Supply for Capital in the Traditional Sector

been specified (at the start of period 0), investment and borrowing decisions will be made contingent on those beliefs and the period 1 equilibrium will be fully determinate, even in states for which there could have been another equilibrium.

However, multiple equilibria and systemic crises are not always possible in fire sale states. Specifically, if the supply schedule is given by S', R$'$ is the unique equilibrium and there can never be a systemic crisis, regardless of beliefs. From (3.15), it is intuitively clear that this is more likely to be the case when the negative x shock is relatively mild. By contrast, if the shock is extremely severe, a crisis could be inevitable – supply schedule S''' depicts this possibility.

3.3.3 The Competitive Equilibrium

We now proceed to solve the model for both 'optimistic' and 'pessimistic' beliefs. Suppose that all agents form a common exogenous belief at the start of period 0 about what equilibrium will arise when multiple equilibria are possible in period 1: if beliefs are 'optimistic', agents assume that there will not be a crisis unless it is inevitable (i.e. unless the supply schedule resembles S'''); if beliefs are 'pessimistic', agents assume that if there is a possibility of a crisis, it will indeed happen. Then, as shown in Appendix A, the competitive equilibrium is characterised by the following repayment ratios associated with each possible state, x_s, where the precise thresholds ($\widehat{x}$, $\widehat{x} - \theta\widehat{q}$ and x^C) depend on beliefs and the distribution of shocks:

$$\text{if } \widehat{x} < x_s, \text{ then } b_{1s} = \theta q_{1s}, \tag{3.18}$$

$$\text{if } \widehat{x} - \theta\widehat{q} < x_s < \widehat{x}, \text{ then } b_{1s} = \theta\widehat{q} - (\widehat{x} - x_s), \tag{3.19}$$

$$\text{if } x^C < x_s < \widehat{x} - \theta\widehat{q}, \text{ then } b_{1s} = 0, \tag{3.20}$$

$$\text{if } x_s < x^C, \text{ then } b_{1s} = \theta q^C = \max[\theta(1 - 2\alpha i_0), 0]. \tag{3.21}$$

Expressions (3.18)-(3.20) correspond to similar expressions in Lorenzoni (2005), though the actual thresholds differ. However, (3.21) is specific to our model and reflects the possibility of systemic financial crises in our setup.

Apart from noting that $\widehat{x} \leq 0$ (since intermediaries will never choose to borrow less than the maximum against states where the realised x is positive), relatively little can be said about the precise location of the thresholds without specifying how the shock is distributed. Section 3.4 determines these thresholds, initial investment, and the state-contingent asset price for a specific distribution.

3.3.4 Discussion of the Competitive Equilibrium

Since expected future returns are positive, the competitive equilibrium always exhibits a high level of credit-financed investment in period 0. As summarised in Table 3.1, subsequent outcomes depend on the realisation of x. In 'good' states, x is positive, investment and credit growth remain strong in period 1, and the economy benefits

State	Realisation of x_s	Description of Outcome
'Good'	$x_s > 0$	Intermediaries do not sell any capital. There is no production in the traditional sector.
'Recession'	x^C or $x^M \leq x_s \leq 0$	Intermediaries sell a portion of their capital but remain solvent (i.e. there are only limited fire sales). Firms continue to operate in the productive sector, but with a lower capital stock than in 'good' states. There is some production in the traditional sector.
'Crisis'	$x_s < x^C$ or x^M	Intermediaries sell all of their capital and go into liquidation. Firms operating in the productive sector shut down. Production only takes place in the traditional sector.

Table 3.1: Summary of Outcomes

from high returns in period 2. Of more interest for our analysis are the 'recession' and 'crisis' states in which x is negative. To further clarify what happens in these cases, we sketch the period 1 repayment ratio, b_1, and asset price, q_1, against x in Figures 3.3 and 3.4 respectively. For illustrative purposes, we present the cases of 'optimistic' and 'pessimistic' beliefs on the same diagram, adding an additional threshold, x^M, to reflect the range of x for which multiple equilibria are possible.[14] However, it is important to bear in mind that the thresholds themselves are endogenous to beliefs.

To explain the repayment ratio function in Figure 3.3, consider what happens when there is a negative x shock (for positive x, $q_1 = 1$, implying that $b_1 = \theta$). As noted above, if the intermediary goes into liquidation as a result of the shock (i.e., if $x_s < x^C$ or x^M, depending on beliefs), it does not need to pay the cost xi_0. In this case, it sells all of its capital at the prevailing market value and repays this 'scrap value' to consumers. Although it may seem unusual that repayments are positive in 'crisis' states (and potentially higher than in 'recession' states), this is entirely optimal. Intuitively, intermediaries have no need for liquidity in 'crisis' states because they shut down and

[14]As for the other thresholds, the location of x^M cannot be computed without specifying the distribution of the shock. However, Figure 3.2 and the associated discussion clearly illustrate how multiple equilibria are only possible over a certain range of x.

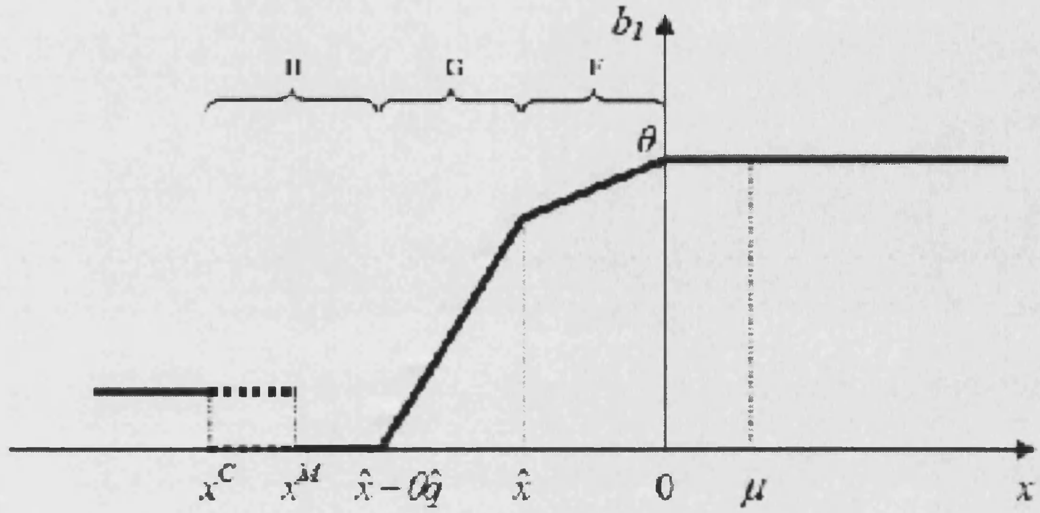

Figure 3.3: The Repayment Ratio as a Function of the Shock

do not pay the cost xi_0. By increasing repayments to consumers in these states, they are able to increase their period 0 borrowing. Since period 0 investment is expected to be profitable, it is, therefore, optimal for intermediaries to promise to repay the entire 'scrap value' of the project to consumers in 'crisis' states.

If, however, the intermediary wants to avoid total liquidation following a negative shock, it must find a way of financing the cost xi_0. Given that it always chooses to borrow the maximum amount it can between periods 1 and 2, the cost can be financed either by reducing repayments to consumers in adverse states or by selling a portion of its capital.

The first option reduces expected repayments to consumers (i.e. $E(b_1)$), lowering the amount that the intermediary can borrow in period 0 (see equation (3.12)) and therefore reducing returns in 'good' states. The expected cost associated with doing this is constant. By contrast, the cost of the second option increases as the asset price falls. So, for mild negative shocks in region F of Figure 3.3, it is better to sell capital because the asset price remains relatively high. The borrowing / repayment ratio in these states remains at its maximum, but this maximum falls slowly as the asset price falls (see

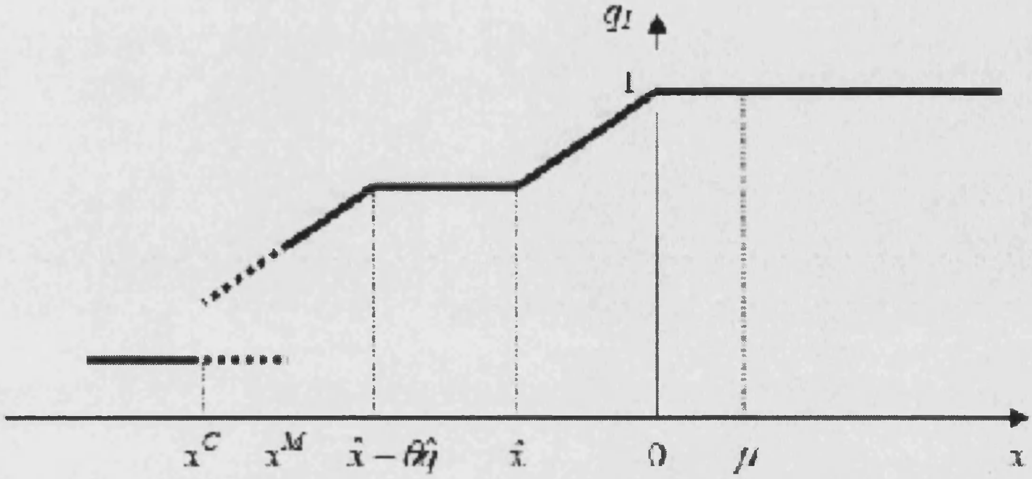

Figure 3.4: The Asset Price as a Function of the Shock

equations (3.5) and (3.18)).

However, when shocks are more severe and fall in region G, the costs of selling capital are so high that it becomes better to reduce repayments to consumers than to sell further capital – this is reflected in (3.19). Eventually, however, the scope for reducing repayments is fully exhausted and the only way to finance the cost is to sell further capital even though the asset price is relatively low (region H). It is at this point that the $b_{1s} > 0$ constraint bites: intermediaries would ideally like to receive payments from consumers in these extremely bad states but are prevented from doing so by limited commitment on the consumer side.[15]

Since the asset price, q_1, only changes when the amount of capital being sold changes, the intuition behind Figure 3.4 follows immediately. For positive x, no capital is ever sold, so the asset price remains at one. However, for negative (but non-crisis) values of x, the asset price falls over those ranges for which intermediaries finance xi_0 by selling additional capital (i.e. for $\widehat{x} < x_s < 0$ and $x_s < \widehat{x} - \theta\widehat{q}$). Meanwhile, in crises, intermediaries sell all of their capital and the asset price is determined by sub-

[15]Since early investment is expected to be profitable, intermediaries have no incentive to set aside liquid resources in period 0 to self-insure against extremely bad states in period 1. But even if some self-insurance were optimal, asset sales would still be forced for sufficiently severe shocks.

stituting (3.16) into (3.17), which gives $q^C = 1 - 2\alpha i_0$. If this expression is negative, returns to capital in the traditional sector fall to zero before all the available capital is being used. In this case, the leftover capital has no productive use in the economy, and $q^C = 0$.

3.3.5 The Constrained Efficient Equilibrium, Efficiency, and the Source of the Externality

We can show that the competitive equilibrium is constrained inefficient by solving the problem faced by a social planner who maximises the same objective function as intermediaries and is subject to the same constraints, but who does not take prices as given. Under certain mild conditions (see Appendix B), the social planner can obtain a welfare improving allocation by reducing intermediaries' borrowing and investment. More specifically, the social planner implements a reduction in borrowing against certain states that has no direct effect on intermediaries' welfare. But it has a potentially important indirect effect: by reducing investment, the amount of capital that has to be sold in fire sale states is reduced, and this both reduces the negative effects of asset price falls, and lowers the likelihood and severity of crises.

The competitive equilibrium thus exhibits over-borrowing and over-investment relative to the constrained efficient equilibrium. In particular, if we view the situation with no frictions (i.e. without borrowing constraints (3.3)-(3.6)) as corresponding to the first-best outcome and the constrained efficient equilibrium as the second-best, then the competitive allocation is fourth-best. This is because policy intervention could feasibly achieve a third-best outcome even if the second-best allocation cannot be attained.

As noted earlier, the limited commitment and potential default to which financial contracts are subject is the key friction in this model. It is straightforward to show that the critical constraint is (3.3): if this were relaxed, the competitive equilibrium would be efficient and there would never be systemic crises because intermediaries would be able to obtain additional payments from consumers in times of severe stress (i.e. when $x_s < \widehat{x} - \theta\widehat{q}$) rather than being forced to sell capital. However, when coupled with decreasing returns to capital in the traditional sector, the presence of this constraint introduces an asset fire sale externality: intermediaries do not internalise the negative effects on asset prices that their own fire sales have. By tightening their budget constraints further, these asset price falls force other intermediaries to sell more capital than they would otherwise have to. In extreme cases, this externality is the source of systemic crises.

3.4 Comparative Statics

We now analyse the effects of financial innovation and changes in macroeconomic volatility on the likelihood and potential scale of systemic crises. This necessitates an assumption about beliefs so that the cut-off value of x below which crises occur is determinate. Accordingly, we suppose that agents have 'optimistic' beliefs, so that crises only occur when they are inevitable.[16]

The shock x is assumed to be normally distributed with mean μ and variance σ^2, where $\mu > 0$. Since analytical solutions for thresholds are unavailable, we present the results of numerical simulations. In our baseline analysis, we assume the following parameter values: $A = 1.5$; $n_0 = 1$; $\mu = 0.5$; $\sigma = 0.5$; $\theta = 0.75$; $\alpha = 0.05$. We then consider the effects of varying σ, θ and α. The empirical relevance of the parameters used is discussed in section 3.4.3.[17]

We measure the likelihood of a crisis by $H(x^C) = \Pr[x < x^C]$ and its scale (impact) in terms of the asset price, q^C, which prevails in it.[18] Lower values of q^C correspond

[16]All of our qualitative results continue to hold if agents have 'pessimistic' beliefs.

[17]The *Matlab* code used for the simulations is available on request from the authors. Robustness checks were also performed by varying the parameters over a range of values.

[18]Recall that crises are associated with total liquidation. So, although the distribution of shocks, $H(x)$,

to more serious crises. To motivate q^C as a measure of the impact of crises, recall that in period 0, consumption goods are turned into capital goods one for one. If some capital goods end up being used in the less-productive sector to produce consumption goods (as happens in a crisis), fewer consumption goods can be produced than were used to buy those capital goods initially. Since a lower q corresponds to reduced returns on the marginal unit of capital in the traditional sector and hence less production of the consumption good from the marginal capital good, the loss associated with a crisis increases as q^C falls. Moreover, lower values of q^C correspond to greater asset price volatility in the economy, further suggesting that it may be an appropriate measure of the scale of systemic instability.

3.4.1 Changes in Macroeconomic Volatility

We interpret a change in macroeconomic volatility as affecting σ. Since x is linked to revenue shortfalls and surpluses, it is reasonable to assume that a reduction in output and inflation volatility (as is likely to be associated with a general reduction in macroeconomic volatility) corresponds to a fall in the standard deviation of x.

Intuitively, a reduction in σ will lower the probability of crises since extreme states become less likely. This is borne out in Figure 3.5(a). However, provided that the mean, μ, is sufficiently above zero and the variance is not too large, a lower standard deviation also makes 'recession' states less likely to occur. As a result, expected repayments to consumers, $E(b_1)$, are higher, meaning that intermediaries can borrow more in period 0. Therefore, initial investment, i_0, is higher. But this means that if a crisis then does arise, more capital will be sold to the traditional sector, the asset price will be driven down further, and the crisis will have a greater impact. This is shown in Figure 3.5(b) and can also be seen by considering a rightward shift of S^L in Figure 3.2.[19]

is continuous, there is only one crisis price, q^C, for all x less than x^C.

[19] If μ is very close to zero and/or σ is very large, it is possible for a reduction in σ to make 'recession' states more likely. This can potentially lead to a reduction in $E(b_1)$ and hence i_0, thus reducing the impact

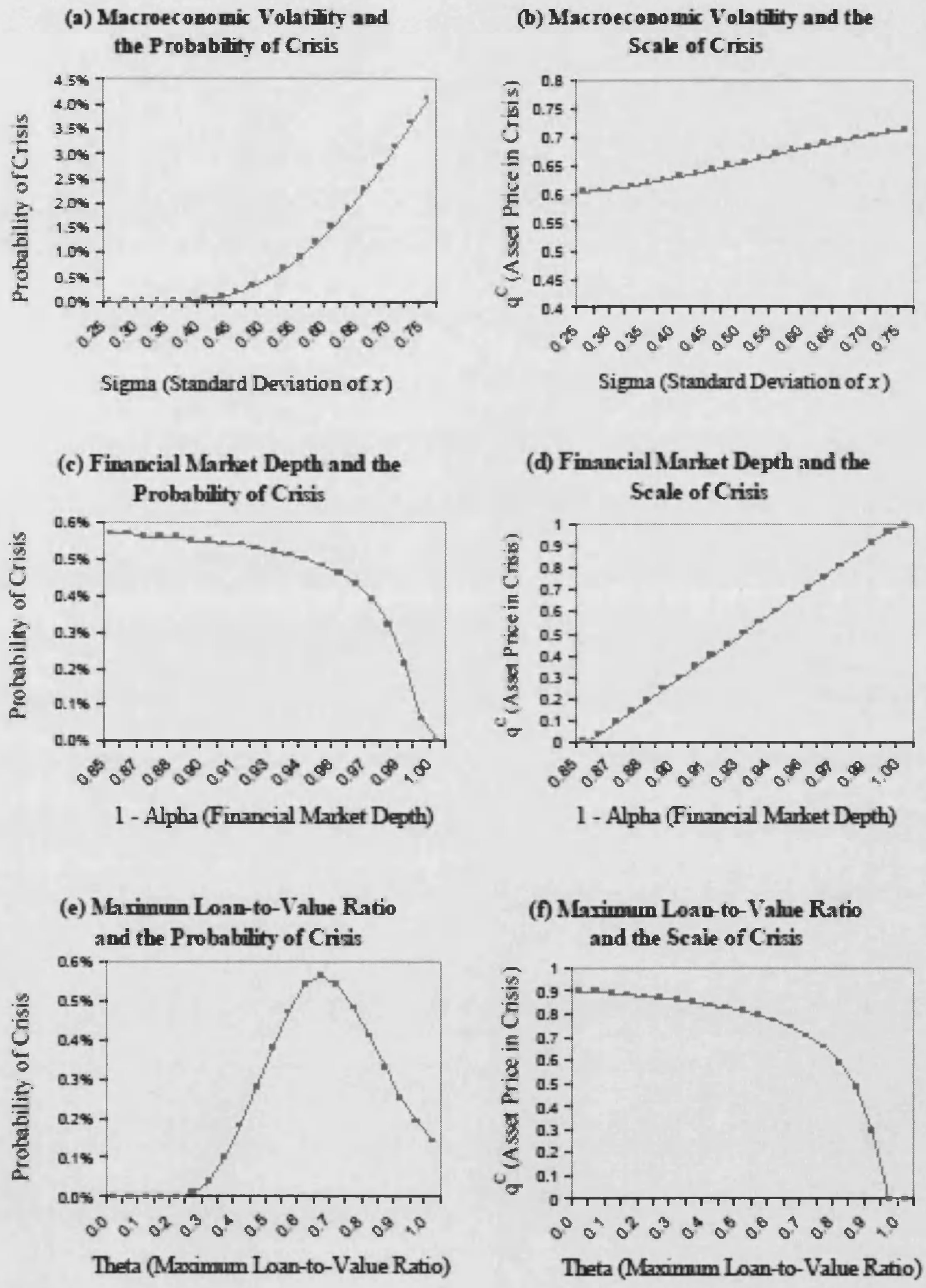

Figure 3.5: Comparative Statics

3.4.2 The Impact of Financial Innovation

We have already argued that financial innovation and recent developments in financial markets can be interpreted as implying higher maximum loan-to-value ratios (higher values of θ) and greater financial market depth (lower values of α). Assuming that the initial value of θ is not particularly low, Figure 3.6(a) illustrates how these changes have made crises less likely (darker areas in the chart correspond to a higher crisis frequency). But from Figure 3.6(b), it is apparent that the severity of crises may have increased (darker areas correspond to a more severe crisis).

To understand the intuition behind these results, we isolate the individual effects of changes in α and θ. Figures 3.5(c) and 3.5(d) suggest that a reduction in α reduces both the likelihood and scale of crises. This is intuitive. If the secondary market for capital is deeper, shocks can be better absorbed and, in the context of Figure 3.2, the demand curve in the traditional sector is flatter. As a result, crises are both less likely and less severe.[20]

By contrast, Figures 3.5(e) and 3.5(f) suggest that an increase in θ increases the severity of crises and has an ambiguous effect on their probability. This is demonstrated more formally in Appendix C. Intuitively, a rise in θ enables intermediaries to borrow more. Therefore, i_0 is higher, and crises will be more severe if they occur. Greater borrowing in period 0 clearly serves to increase the probability of crises as well. However, a rise in θ also means that intermediaries have greater access to liquidity in period 1: specifically, they have more scope to reduce period 1 repayments to consumers. This effect means that they are less likely to go into total liquidation, making crises less likely.

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of crises. Since the numerical results suggest that this only happens for fairly extreme combinations of the mean and variance, we view the case discussed in the main text as being more likely. However, this feature does have the interesting implication that crises could be most severe in fairly stable and extremely volatile economies.

[20]This analysis assumes that secondary markets continue to function with the onset of a crisis. However, α itself could be endogenous and change during periods of stress. So reductions in α in benign times may have little effect on the severity of crises.

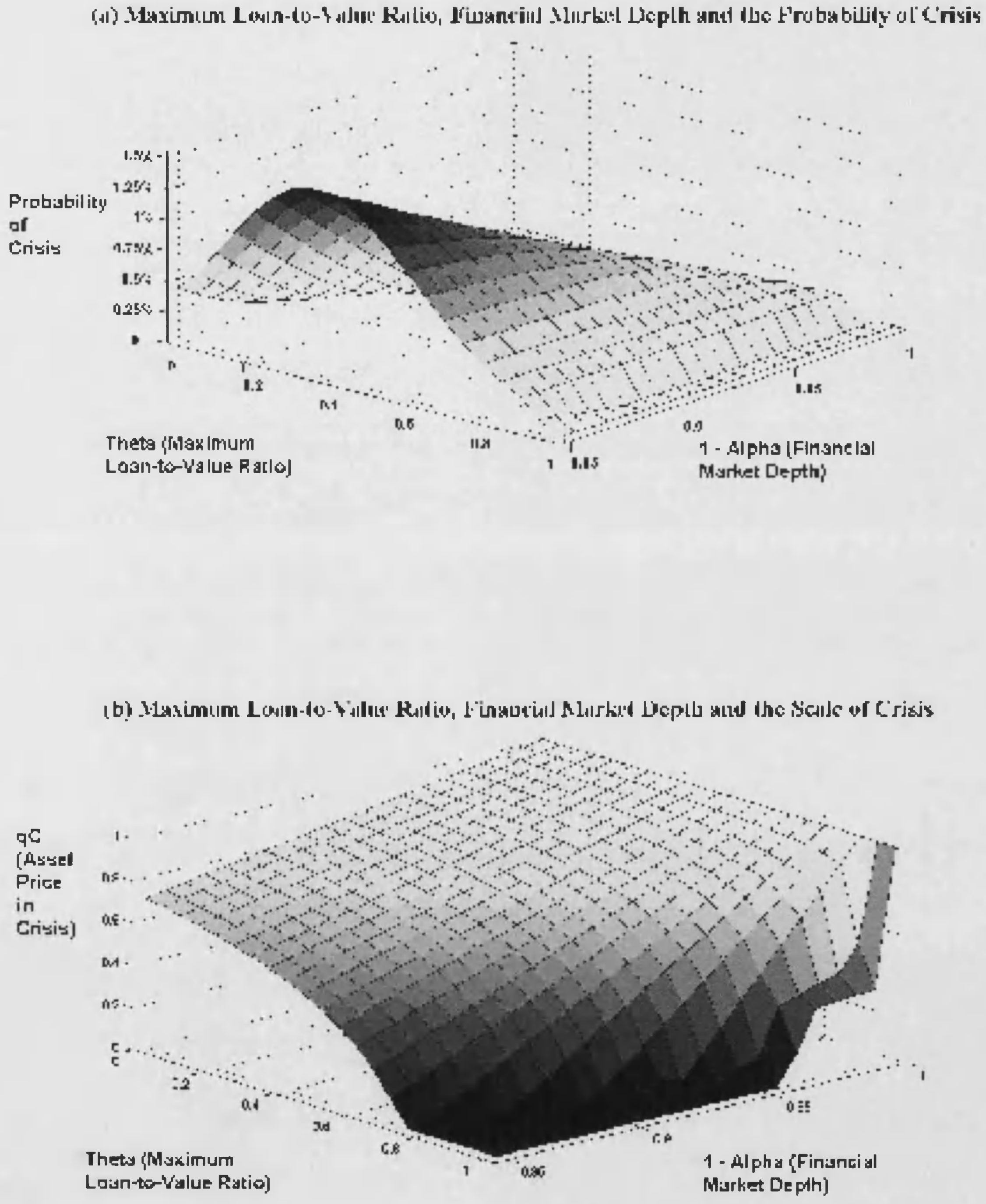

Figure 3.6: Financial Innovation and the Probability and Scale of Crises: 3D Charts

Figure 3.5(e) shows that crises are most frequent for intermediate values of θ, suggesting that middle-income emerging market economies may be most vulnerable to systemic instability.[21] By contrast, countries with extremely well-developed or very underdeveloped financial sectors, with high / low maximum loan-to-value ratios, are probably less vulnerable to crises.

3.4.3 Comments on the Quantitative Results

Although our numerical analysis is intended to be illustrative, the baseline case is broadly consistent with several features of the data. As would be expected, the leverage ratio of assets to equity implied by the model is closely tied to the value of θ. With θ set to be 0.75, the implied leverage ratio is 3.5, which is reasonably close to the estimate of 4.9 for average hedge fund leverage over 1996-2004 reported by McGuire *et al.* (2005).

The mean and variance of the shock are chosen in relation to each other and are key determinants of the likelihood of 'recessions' and crises. If a period is taken as one year, the baseline parameter values yield 'recessions' once every six and a half years and crises once every 200 years. In 'recession' states, the average short-run loss which intermediaries have to finance is 24% of the initial amount invested; in crises, the reinvestment cost needed to continue operations (which intermediaries choose not to pay) is almost as much as the initial amount invested. Price falls in adverse states are strongly influenced by α – in the baseline calibration, the average price discount in 'recession' states is 17%, while the price falls by 35% in crises. These figures are broadly consistent with the 30% price discount identified by Pulvino (1998) for commercial aircraft sales in depressed markets and the 7.9% price discount for fire sale stocks reported by Coval and Stafford (2007), especially when we consider that equities are amongst the most liquid assets, whilst aircraft are probably amongst the most illiquid assets.

[21] Aghion *et al.* (2004) present a similar result but their approach is quite different, focussing on the effects of fluctuating real exchange rates and international capital flows in a small open economy model.

3.4.4 Discussion

The comparative static analysis highlights the potential risk of more severe crises as a result of financial innovation and greater macroeconomic stability. But this should not necessarily be taken to imply that these developments are undesirable. In particular, higher values of θ and lower values of σ both imply greater investment in period 0 and, as such, may increase welfare.

All of our results were obtained under the assumption that θ is not state-contingent. But *ex post* changes in θ in period 1 can affect outcomes. In particular, it is clear from (3.15) that when i_0 is strictly greater than k_s^T, an unanticipated increase in θ in period 1 states with a negative x will shift the supply curve for capital in the traditional sector to the left. As a result, there will be fewer cases in which crises are inevitable. In addition, the price fall in 'recession' states will be lower. Intuitively, the *ex post* increase in θ enables intermediaries to access more liquidity in period 1, meaning that they do not need to sell as many assets to the traditional sector to continue operations. On the other hand, falling maximum loan-to-value ratios during downturns could have detrimental effects.

This result suggests that a rule to increase θ in adverse states may be welfare-improving, though a full analysis would clearly require solving the model under the assumption that, when making initial investment decisions, intermediaries know that θ may be adjusted in period 1. As such, the model illustrates how there may sometimes be scope for policymakers to promote liquidity. One specific approach, discussed by Borio *et al.* (2001), is the pursuit of discretionary policy towards collateral valuation practices during periods of stress. For example, as noted by Borio (2004), supervisory authorities in Japan lowered margin requirements and relaxed lending limits on collateral assets in order to alleviate liquidity constraints and contain distress selling during the 1987 stock market crash. More generally, the welfare consequences of policies that induce market participants to hold liquidity cushions at business-cycle frequencies

– building up liquidity during booms and drawing it down during recessions – merit closer investigation.

3.5 Conclusion

This paper analysed a theoretical general equilibrium model of intermediation with financial constraints and state-contingent contracts containing a clearly defined pecuniary externality associated with asset fire sales during periods of stress. After showing that this externality was capable of generating multiple equilibria and systemic financial crises, we considered the effects of changes in macroeconomic volatility and developments in financial markets on the likelihood and severity of crises. Together, our results suggest how greater macroeconomic stability and financial innovation may have reduced the probability of systemic financial crises in developed countries in recent years. But these developments could have a dark side: should a crisis occur, its impact could be greater than was previously the case.

The paper sheds light on cross-country variation in the likelihood and scale of financial crises. Macroeconomic volatility is generally higher in developing countries than in advanced economies but maximum loan-to-value ratios are invariably lower. Given this, our results predict that crises in emerging market economies should be more frequent but less severe than in developed countries. The first of these assertions is clearly borne out by the data (Caprio and Klingebiel, 1996, Table 1; Demirguc-Kunt and Detragiache, 2005, Table 2). Although the second is more difficult to judge given the rarity of financial crises in developed countries in recent years, the length and depth of the Japanese financial crisis of the 1990s suggests that such intuition is plausible. Moreover, in terms of output losses, Hoggarth *et al.* (2002) find that crises in developed countries do indeed tend to be more costly than those in emerging market economies.

3.A Appendix

3.A.1 The Competitive Equilibrium

In this appendix, we solve the model for the competitive equilibrium when all agents have 'optimistic' beliefs about what equilibrium will arise in states in which multiple equilibria are possible. Specifically, they believe that crises only happen when they are inevitable and never occur when there are multiple equilibria. If agents have 'pessimistic' beliefs, the derivation proceeds along very similar lines.

Conditional on beliefs, the equilibrium is unique, and can be fully characterised by the three cut-off values for the aggregate shock x shown in expressions (3.18)-(3.21). These cut-offs determine four intervals in the distribution of x (i.e. in the distribution of possible states). In each of these intervals, intermediaries' incentives to protect their net worth, and hence their decisions about optimal repayments, will be different. We show how the equilibrium can be fully characterised by these three cut-off points and how, conditional on beliefs, it is unique.

Define the subset C as the (endogenous) set of states where there is a crisis. Then the return, z_s, that intermediaries obtain in period 2 in state s from one unit of their net worth in state s in period 1 is given by:

$$z_s = \begin{cases} \frac{A-\theta}{q_{1s}-\theta} & \forall s \notin C \\ 1 & \forall s \in C \end{cases}. \tag{3.22}$$

To derive this expression, note that in non-crisis states in period 1, a given amount of net worth, n_1, can be leveraged to obtain a total investment by intermediaries of $q_{1s}k_s = n_1 + \theta k_s$. In other words, each unit of net worth is leveraged by a factor of $1/\left(q_{1s}-\theta\right)$. Since the return per unit of capital after payment of liabilities is $A-\theta$ (recall that $b_{2s}=\theta$), return per unit of net worth in non-crisis states is therefore $\left(A-\theta\right)/\left(q_{1s}-\theta\right)$. By contrast, in crisis states, intermediaries do not invest, so the marginal return to net worth is just its consumption value of one.

Meanwhile, the return, z_0, that intermediaries obtain in period 2 by investing one unit of their net worth in period 0 is given by:

$$z_0 = E_{s \notin \mathbf{C}} \left[z \frac{x + q - b_1}{1 - E(b_1)} \right] \Pr[s \notin C] + E_{s \in \mathbf{C}} \left[\frac{q - b_1}{1 - E(b_1)} \right] \Pr[s \in C]. \tag{3.23}$$

This is the expected value of the product of period 1 and period 2 returns. The period 1 return may be explained along similar lines to the period 2 return. The factor by which intermediaries leverage one unit of period 0 net worth to purchase capital is $1 - E\,(b_1)$. In non-crisis states, the return per unit of capital is $x_s + q_{1s} - b_{1s}$. However, since intermediaries that fully liquidate do not pay the cost $x_s i_0$, the return per unit of capital in crisis states is $q_{1s} - b_{1s}$.

States can be divided into four sets: $S_1 = \{s : 1 < z_s < z_0\}$, $S_2 = \{s : z_s = z_0\}$, $S_3 = \{s : z_s > z_0\}$, and $\mathbf{C} = \{s : z_s = 1 < z_0\}$.We want to show that these sets cover the whole distribution of x, with S_1 covering states from $+\infty$ to $\widehat{x}(< 0)$, S_2 from $\widehat{x}$ to $\widehat{x} - \theta\widehat{q}$, S_3 from $\widehat{x} - \theta\widehat{q}$ to x^C, and $\mathbf{C}$ from x^C to $-\infty$.

Consider a state s that belongs to S_1. We want to show that if $x_{s'} > x_s$, then $s' \in S_1$. In state $s \in S_1$, borrowing will be at its maximum possible level in period 0 ($b_{1s} = \theta q_{1s}$) because $z_0 > z_s$, and the price of capital will satisfy $q_{1s} = F'[\max(k_s^T, 0)]$. If $x_{s'} > x_s > 0$, then there are no fire sales and $q_{1s} = q_{1s'} = 1$, and $z_s = z_{s'}$. If $0 > x_{s'} > x_s$, then $k_{s'}^T < k_s^T$, $q_{1s} < q_{1s'}$ and $z_{s'} < z_s$. In both cases, $z_{s'} < z_0$ and hence s' belongs to S_1.

The threshold for x that separates S_1 and S_2 is $\widehat{x}$. It is the value for which, in equilibrium, $z_0 = z_s$ and there is maximum borrowing ($q_{1s} = \widehat{q}$ is the equilibrium price in that state). For all states in $S_2 = \{s : z_s = z_0\}$, q_{1s} has to be constant, and given that i_0 is constant in all states in S_2, the amount borrowed in each state is pinned down and given by $b_{1s} = \theta\widehat{q} - (\widehat{x} - x_s)$. The second cut-off, $\widehat{x} - \theta\widehat{q}$, is the value of x for which $b_{1s} = 0$ and $z_s = z_0$. As x decreases beyond $\widehat{x} - \theta\widehat{q}$, the repayment / borrowing ratio cannot be reduced any further. Therefore, more capital is sold in the secondary market, implying that $q_{1s} < \widehat{q}$ and hence $z_s > z_0$. Following the same logic as when we show that all values above $\widehat{x}$ belong to S_1, it is straightforward to show that all values below $\widehat{x} - \theta\widehat{q}$ but above the crisis threshold, x^C, belong to S_3. (It is important to note at this point that we are assuming that whenever it is possible to have multiple equilibria, 'optimistic' self-fulfilling beliefs imply that the 'recession' equilibrium arises rather than the 'crisis' equilibrium. We do not specify the precise set of multiple equilibria states, as this set is itself endogenous and a function of beliefs.)

To complete the characterisation, we need to show that there is a threshold, x^C, below which crises are unavoidable, and find conditions under which this threshold is lower than $\widehat{x} - \theta\widehat{q}$. The solution for x^C is obtained by solving the system of two equations that results from equating the demand and supply curves and their slopes. It is given by:

$$x^C = -\left[\frac{(1-\theta)^2}{8\alpha i_0} + \theta\right]. \tag{3.24}$$

An exact analytical condition for x^C to be lower than $\widehat{x} - \theta\widehat{q}$ requires an assumption about the distribution of x. In our numerical exercises we check that this condition is satisfied, finding that it is for most parameter values.

3.A.2 The Social Planner's Solution

The social planner's optimisation problem is given by:

$$\max_{i_0,\{k_s\},\{b_{1s}\}} E_0\left(\pi_1 + \pi_2\right) = \max_{i_0,\{k_s\},\{b_{1s}\}} E_{s\notin\mathbf{C}}\left[\frac{A-\theta}{q-\theta}(x+q-b_1)i_0\right]\Pr[s\notin\mathbf{C}]$$
$$+E_{s\in\mathbf{C}}\left[\left(q-b_1\right)i_0\right]\Pr[s\in\mathbf{C}]$$

subject to:

$$i_0 = n_0 + E(b_1)\, i_0 - \tau, \tag{3.25}$$

$$k_s^T q_{1s} = -(x_s - b_{1s})\, i_0 - \left(i_0 - k_s^T\right)\theta \quad \forall s\text{: partial or no liquidation } (s \notin \mathbf{C}), \tag{3.26}$$

$$0 \le b_{1s} \le \theta q_{1s} \qquad \forall s, \tag{3.27}$$

and:

$$E\left[3e + \tau + F(k^T) - qk^T - w\right] \ge U^{CE}, \tag{3.28}$$

where $\mathbf{C}$ is the set of crisis states, U^{CE} is the utility of consumers under the competitive equilibrium, τ is a transfer from intermediaries to consumers, $F\left(k^T\right) - qk^T$ represents profits to consumers from production in the traditional sector, $w = -\lambda x$ is the cost of a financial crisis to consumers, and $0 < \lambda < 1$.

Condition (3.28) requires that consumers are at least as well off in the constrained efficient equilibrium as in the competitive equilibrium. To satisfy this condition, the social planner implements any necessary transfer, τ, from intermediaries to consumers in period 0. The key difference between the social planner and representative intermediary problems is that the social planner does not take the asset price, q_{1s}, as given.

Since $q_{1s} = F'\left(k_s^T\right)$ and since $k^T = i_0$ in crisis states, the social planner's problem can be rewritten as:

$$\begin{aligned} &\max_{i_0,\{k_s\},\{b_{1s}\}} E_0\left(\pi_1 + \pi_2\right) \\ &\quad = \max_{i_0,\{k_s\},\{b_{1s}\}} E_{s\notin\mathbf{C}}\left\{\frac{A-\theta}{F'\left(k^T\right)-\theta}\left[x + F'\left(k^T\right) - b_1\right] i_0\right\} \Pr[s \notin \mathbf{C}] \\ &\qquad\qquad + E_{s\in\mathbf{C}}\left\{\left[F'\left(i_0\right) - b_1\right] i_0\right\} \Pr[s \in \mathbf{C}] \end{aligned}$$

subject to:

$$i_0 = n_0 + E(b_1)\, i_0 - \tau, \tag{3.29}$$

$$k_s^T F'\left(k_s^T\right) = -\left(x_s - b_{1s}\right) i_0 - \left(i_0 - k_s^T\right)\theta \quad \forall s\text{: partial or no liquidation } (s \notin \mathbf{C}), \tag{3.30}$$

$$0 \leq b_{1s} \leq \theta F'\left(k_s^T\right) \qquad \forall s, \tag{3.31}$$

and:

$$E\left[3e + \tau + F\left(k^T\right) - F'\left(k^T\right) k^T - w\right] \geq U^{CE}. \tag{3.32}$$

To show that the competitive allocation is not constrained efficient, it is sufficient to show that the social planner can increase welfare by decreasing borrowing and investment in period 0. Such a change has several effects:

1. It reduces welfare by lowering the level of *ex ante* investment, i_0.

2. It increases welfare by reducing liabilities, b_{1s}, in certain states.

3. It reduces the amount of capital that has to be sold in fire sale states, increasing the asset price in those states.

4. It reduces the likelihood of a crisis.

We wish to determine when the net effect on welfare is positive. The positive contributions to welfare arise directly from the lower level of asset sales in fire sale states, and indirectly from a decrease in the likelihood of a crisis. We derive a condition under which the direct mechanism alone gives a positive net effect. Considering the indirect effect would strengthen our results but the analysis depends on the specific distributional assumptions taken and there is generally no closed-form solution.

Starting from the competitive allocation, suppose the social planner reduces *ex ante* investment by Δi_0 and reduces borrowing by the same amount against states in which

$z_0 = z_s$ (z_0 and z_s are *ex ante* and *ex post* returns, as defined in Appendix A). First note that reducing borrowing against these states has no negative welfare effect on intermediaries since they are indifferent between investing *ex post* in them and *ex ante* in general. Therefore, to determine whether the reduction in i_0 is welfare-improving, we simply need to consider whether the welfare cost to consumers can be fully compensated for by any gain to intermediaries.

Differentiating the market clearing condition for used capital (which is obtained by equating supply, (3.15), and demand (3.17)), we can see that the reduction in i_0 decreases the amount of capital sold in 'recession' states by:

$$\frac{dk_s^T}{di_0} = \frac{x_s + \theta - b_{1s}}{[F'(k^T) - \theta] + F''(k^T)\, k^T}. \tag{3.33}$$

The profit consumers obtain from operating their technology is $F\left(k^T\right) - F'\left(k^T\right) k^T$. Therefore, in 'recession' states, the reduction in i_0 has a direct welfare cost to consumers of:

$$\rho_s = \frac{d\left[F\left(k^T\right) - F'\left(k^T\right) k^T\right]}{dk_s^T}\frac{dk_s^T}{di_0} = -\frac{x_s + \theta - b_{1s}}{[F'(k^T) - \theta] + F''(k^T)\, k^T} F''\left(k^T\right) k^T. \tag{3.34}$$

Intuitively, ρ_s represents the amount of goods transferred in 'recession' states from consumers to intermediaries as a result of the social planner's implementation of an equilibrium with lower borrowing than the competitive equilibrium. Intermediaries have to transfer at least this amount to consumers (in period 0, when they have resources to do so) to compensate them for this loss. What needs to be shown is that the net effect of this transfer is positive for intermediaries.

This will be the case if:

$$E(\rho)\, z_0 < E(\rho z). \tag{3.35}$$

The left hand side of (3.35) is the cost of the transfer to intermediaries and the right hand side is the benefit. In period 0, intermediaries transfer $E(\rho)$ goods to consumers, which they could have invested at a return z_0. On the other hand, intermediaries now have extra resources of ρ_s in each 'recession' state in period 1. Since returns on additional capital in period 1 are z_s, the expected benefit from these extra resources is $E(\rho z)$. Without specifying the distribution of x and the parameter values, we cannot be specific about when this inequality is satisfied. However, provided that the distribution of x has sufficient variance, so that states in which $z_s > z_0$ are not very isolated events, it is generally satisfied (note that the positive correlation between ρ and z helps in this regard). If this is the case, welfare is unambiguously higher under the social planner's allocation than under the competitive equilibrium.

3.A.3 Implications of Changes in the Maximum Loan-to-Value Ratio

In this appendix, we show that increases in the maximum loan-to-value ratio, θ, heighten the scale of crises but have an ambiguous effect on their probability. Recall that we measure the likelihood of a crisis by $H(x^C) = \Pr[x < x^C]$ and its scale in terms of the asset price, q^C, which prevails in it.

We start by analysing the scale of crises. Substituting (3.16) into (3.17) gives the asset price in crises:

$$q^C = 1 - 2\alpha i_0. \tag{3.36}$$

In general, if θ increases, intermediaries can borrow more against those states in which they are constrained, which serves to increase their initial investment, i_0. There are only two channels through which intermediaries' investment could be reduced by an increase in θ. First, there is a general equilibrium channel by which an increase in θ may decrease the price of second hand capital in certain states, thus reducing the value of collateral in those states and, hence, reducing borrowing against those states. But this can only happen if, overall, initial investment has increased as a result of the increase in θ – as such, it can only ever be an offsetting channel. Second, an increase in θ may lower the likelihood of crises, which could reduce *ex ante* borrowing given that borrowing is positive against crisis states but may be zero against certain 'recession' states (see Figure 3). However, this effect has very little significance since crisis states are much rarer than states in which intermediaries are constrained. Given this, it follows that initial investment, i_0, is a positive function of θ. From (3.36), this implies that crises become more severe as the maximum loan-to-value ratio rises.

In terms of the probability of crisis, first note that from (3.24), the crisis threshold below which crises are unavoidable is given by:

$$x^C = -\left[\frac{(1-\theta)^2}{8\alpha i_0} + \theta\right]. \tag{3.37}$$

Differentiating with respect to θ gives:

$$\frac{\partial x^C}{\partial \theta} = \frac{\partial x^C}{\partial \theta} + \frac{\partial x^C}{\partial i_0}\frac{\partial i_0}{\partial \theta} \tag{3.38}$$

$$= \left[\frac{1-\theta}{4\alpha i_0} - 1\right] + \frac{(1-\theta)^2}{8\alpha i_0^2}\frac{\partial i_0}{\partial \theta}. \tag{3.39}$$

When $\theta = 1$, this expression is negative, implying that the crisis threshold is falling and crises becoming less likely as θ increases. So, in the vicinity of $\theta = 1$, it must be the case that increases in the maximum loan-to-value ratio reduce the probability of crises. The case where $\theta = 0$ is less clear cut as the sign of the first term in (3.24) is ambiguous. But, when $\theta = 0$, initial investment by intermediaries, i_0, is restricted to their initial net worth, n_0. Therefore, if initial net worth is sufficiently small, the first term in (3.39) is positive when $\theta = 0$, as is the whole expression, implying that the likelihood of crises is increasing in θ. So, increases in θ have an ambiguous effect on the probability of crises, serving to reduce their probability for high values of θ but generally increasing their probability for low values of θ.

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