Equilibrium Credit Spreads and the Macroeconomy*

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July 2010

ABSTRACT

The Great Recession of 2008 offers a primary example of the important role that fluctuations in credit risk play in the aggregate economy. In this paper we explore this link with a tractable general equilibrium asset pricing model with heterogeneous firms. Our model produces realistic movements in risk premia in equity and corporate bond markets and shows how this is an important determinant of aggregate fluctuations following both technology and pure credit shocks. We also show that movements in credit spreads forecast recessions by predicting future movements in corporate investment.

*We are grateful to comments from participants at seminars in Carnegie-Mellon, Duke, Wharton, NY Fed, ECB, and Imperial College, as well as the following conferences: AFA, SED, Minnesota Macro Week, Rimini Macro-Finance, LAEF, Venice C.R.E.D.I.T, and ESSFM Gerzensee. All errors remain our own.

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1 Introduction

The Great Recession of 2008 illustrates the need for a deeper understanding of the links between developments in financial markets and fluctuations in aggregate economic variables. Attempts to provide an integrated discussion of these issues in a modern setting have gathered speed recently but there is still no agreed upon framework that can captures the essential features of the data.

Most efforts by financial economists have largely been focused on attempting to explain the magnitude of credit risk by linking it, first, with the financing decisions of firms and, more recently, and also more successfully, with exogenous movements in risk premia and aggregate factors.[1] By contrast most general equilibrium models used in macroeconomics have attempted to explain the cyclical behavior of asset markets quantities and their correlation with macroeconomic aggregates while largely ignoring the role of variations in risk premia.[2]

We believe that each of these parallel but separate approaches offers an incomplete picture of the importance of financial markets in macroeconomic models while neglecting important ideas and facts. In this paper we focus instead on integrating the core state-of-the-art ideas from each of these approaches in a tractable general equilibrium model with heterogeneous firms making optimal investment and financing decisions under uncertainty. Macroeconomic quantities are obtained by aggregating across the optimal decisions of each firm and required to be consistent with consumption and savings decisions of a representative household/investor.

[1]Building on Leland (1994) recent quantitatively successful contributions include Hackbarth, Miao, Morellec (2006), Chen, Collin Dufresne, Goldstein (2008), Chen (2008), Bhamra, Kuhn, and Strebualev (2008).

[2]Classic examples include Carlstrom and Fuerst(1997), Kyotaki and Moore (1997) and Bernanke, Gertler, and Gilchrist (1999). Some recent examples are Lorenzoni and Karl Walentin (2007) and Philippon (2008).

By integrating corporate investment and capital structure decisions into an asset pricing model, we endogenously link movements in aggregate quantities such as investment and output to the prices of stocks and bonds. As a result we show that movements in financial variables such as credit spreads and expected equity returns will forecast future economic activity.

Unlike almost all existing macro models however, movements in credit prices in our model are largely driven by fluctuations in credit risk premia and not solely by changes in average default rates. Intuitively this happens because, in our model, default losses occurs precisely when marginal utility is high, exacerbating the countercyclical nature of credit spreads. Moreover, in our equilibrium setting, endogenous and costly default increases the volatility of consumption in recessions, thereby rendering the market price of risk sharply countercyclical as well. By contrast, macroeconomic models relying solely on variation in aggregate default rates usually generate unrealistic levels and cyclical patterns for credit spreads and leverage ratios.

Because investors require higher compensation for default risk in bad times, firms find it especially costly to obtain debt financing, thereby depressing investment and output while amplifying macroeconomic shocks. Risk premia in corporate bond markets are thus propagated into the real economy and generate a strong correlation between observed credit spreads and macro aggregates. In our model the credit risk premium emerges as the common link between credit markets, equity markets and macroeconomic aggregates.

The joint endogeneity of credit risk and macro quantities also implies that, in our model, both the IES and risk aversion matter separately for aggregate quantities, a result that contrasts with the more common view in the macro literature where risk aversion (and risk premia) is generally ignored.[3]

[3] An elegant example is Tallarini's (2000) separation result where risk aversion governs asset prices

While qualitatively we are able to replicate all the predicted cyclical patterns in macro and financial variables the model also performs reasonably well quantitatively. Not only does accounting for the premia in corporate bond prices allows us to generate sizeable credit spreads but, in addition, we find that allowing for endogenous movements in credit markets further enhances the model's ability to match several key stylized facts about macro aggregates and equity markets with a reasonable amount of aggregate volatility.

While our focus is on aggregate data our approach expands upon a recent set of contributions in finance seeking to understand the level and dynamics of credit spreads in relation to macroeconomic shocks.[4] We add to this literature by adopting a truly general equilibrium perspective that allows us to study the endogenous interactions between credit, equity markets and macroeconomic variables.

Methodologically, our model also connects the corporate finance literature on optimal capital structure and investment with the asset pricing literature on aggregate risk premia in a macroeconomic setting. While a little stylized, the model is extremely tractable and provides a flexible environment for a quantitative analysis of the interactions between frictions at the corporate level, asset prices and macroeconomic fluctuations.

Many researchers have documented the role of asset market movements in both predicting and amplifying macroeconomic fluctuations. In particular, movements in credit spreads - the difference between corporate and treasury yields - have been shown to carry important information both about future movements in real activity and equity markets. Credit spreads are both large and volatile, as well as strongly countercyclical. A long literature has documented that credit spreads forecast both output and

alone while the IES determines economic aggregates.

[4]A list of recent papers in this area includes Hackbarth, Miao, Morellec (2007), Chen, Collin Dufresne, Goldstein (2008), Chen (2008), Bhamra, Kuhn, and Strebualev (2008).

investment growth as well as future stock returns and stock market volatility.[5,6]

Finally our work also adds to the literature on equilibrium asset pricing with heterogeneous firms.[7] From this point of view the novelty in our work is that we explicitly allow for deviations from the Modigliani-Miller theorems so that corporate financing decisions affect investment, and thus asset prices and output. Finally, our paper is related to recent work on corporate capital structure and financing decisions across the business cycle.[8]

The rest of the paper is organized as follows. Section 2 describes our basic general equilibrium model and some of its properties, while section 3 discusses the details associated with solving it numerically. Our findings are covered in section 4 and the final section concludes.

2 The Model

In this section we describe a general equilibrium with heterogeneous firms that are financed with both debt and equity. Debt is used because of its tax benefits. Although our economy is often stylized the model presented here preserves tractability and economic intuition. Nevertheless as we will see below this economy is also suitable for detailed quantitative analysis.

[5] Examples of the ability of credit spreads to forecast economic activity include studies by Stock and Watson (1991), Lettau and Ludvigson (2004), Gilchrist and Zakrajsek (2008), and Mueller (2008)

[6] Examples of the link between credit spreads and equity markets include Keim and Stambaugh (1986), Schwert (1989) and Fama and French (1992).

[7] Gomes, Kogan, and Zhang (2003), Gourio (2006), Gala (2006).

[8] Covas and Den Haan (2007), Bhamra, Kuhn and Strebulaev (2008b), Hennessy and Levy (2006).

2.1 Production Sector

The production sector of the economy is made of a continuum of firms that differ in their productivity, size and leverage among other characteristics. In characterizing the problem of firms in this section we take the stochastic discount factor for the economy as given. Later we show how this is determined in general equilibrium by the optimal consumption and savings decisions of households.

2.1.1 Technology and Investment

All firms produce the same homogeneous final good that can be used for either consumption or investment. The production function denoting the instantaneous flow of output is described by the expression:

$$y(x, z, k) = xzk \tag{1}$$

where x and z denote the values of aggregate and firm specific productivity, respectively. The behavior of these follows a first order autoregressive process with normal innovations:

$$\log(x_t) = \rho_x \log(x_{t-1}) + \sigma_x v_{xt},$$

$$\log(z_t) = \rho_z \log(z_{t-1}) + \sigma_z v_{zt},$$

where both v_{xt} and v_{zt} are independently and identically distributed shocks drawn from a standard normal distribution.[9]

The variable k denotes the firm's productive capacity. This capacity is installed when the firm begins to operate and remains fixed throughout the life of the firm. These

[9] A small but growing literature has begun to investigate the importance of non-normal or disaster shocks or even time variation in volatility (recent examples include Drechsler and Yaron (2010) and Gourio (2010)). Although these features are absent from our shock processes, our model endogenously generates them in the aggregate quantities.

assumptions imply that our aggregate economy experiences stochastic and persistent variation in its growth rate over time through fluctuations in aggregate productivity, x_t.

2.1.2 Firm Entry and Financing

New firms enter the market and start production if market conditions are sufficiently attractive. Entering firms draw the initial realization of the idiosyncratic shock z from its long-run invariant distribution, denoted $G(z)$. For simplicity we assume that this value is only observed *after* entry. We further assume that entering firms are not immediately productive.

Entering firms must invest to build their productive capacity, k. This investment can be financed with either debt or equity finance. Debt takes the form of a consol bond that pays a fixed coupon bk as long as the firm is in existence and does not default on its obligations. Defining the coupon as bk allows us to interpret b as a measure of book leverage.

2.1.3 Equity Value and Exit

Given production and leverage the firm's per-period operating profits are given by the expression:

$$\pi(x, z, b, k) = (xz - b)k \tag{2}$$

To economize on notation let s denote the aggregate state of the economy, which includes the state of aggregate productivity, x. Taking the households pricing kernel, M, as given, the firm's equity value, $V(s, z, k, b)$ *after* entering the economy is determined through the Bellman equation:

$$V(s, z, b, k) = \max\{0, (1-\tau)(1-\lambda)(xz - b)k + E[M(s, s')V(s', z', b, k)]\} \tag{3}$$

where τ is the marginal tax on corporate profits, adjusted for taxes on distributions and personal interest income and λ is an indicator function that takes the value of 0 when equity distributions are positive and captures the costs of issuing any new equity. As usual we have used the notation s' to denote the future value of s. Finally note that our assumptions about the nature of cash flows implies that equity value is linear in k. Thus we can work instead with the market to book ratio:

$$Q(s,z,b) = V(s,z,b,k)/k. \tag{4}$$

The Bellman equation (3) implies that equity holders will default on their debt obligations when equity value falls to zero. This yields a default cutoff value for the idiosyncratic shock, $\bar{z}_d(s,b)$, such that the firm will default whenever $z < \bar{z}_d(s,b)$. Formally, we define this default threshold with the condition:

$$z_d(s,b) = \min\{z : v(s,z,b) = 0\} \tag{5}$$

2.1.4 Value of Debt and Credit Spreads

Bondholders receive the coupon bk when the firm does not default. If the firm defaults its current assets (capital plus current output) are liquidated and the proceeds are used to pay the creditors. We assume however that a fraction ϕ is lost in liquidation. Formally then, we can define the market value of debt, $B(s,z,b)$, normalized per unit of capital k, in recursive form as follows:

$$B(s,z,b) = [b + E[M(s,s')B(s',z',b)]]\chi_{\{z>\bar{z}_d\}} + (1-\phi)(1+xz)(1-\chi_{\{z>z_d\}}) \tag{6}$$

Here χ is an indicator function that takes the value of 1 when the firm defaults so that $z > \bar{z}_d(s,b)$.

It is now straightforward to define the yield $y(s,z,b)$ on corporate debt as:

$$y(s,z,b) = b/B(s,z,b) \tag{7}$$

To construct measures of the credit spread for this economy we compare this yield with that on a riskless bond of identical maturity. Formally then, our measure of credit spreads is:

$$cs(s,z,b) = y(s,z,b) - y_f(s,z,b) \tag{8}$$

where $y_f(s,z,b)$ is the yield on a bond of identical characteristics but assuming no default occurs. This risk free bond is then similar to a AAA rated bond instead of a pure treasury.[10]

2.1.5 Entry and Investment

Each period a mass of potential new entrants arrives in the economy. Each of these firms is endowed with an investment opportunity that expires at the end of the current period.

Given the expression for equity and debt value, the expected value of entry for any of these firms, is given by the expression:

$$A_0(s,b) = \int Q(s,z,b) + B(s,z,b)dG(z) \tag{9}$$

New entrants build up the required productive capacity, k, by incurring a unit cost of installation e. This cost is randomly drawn from a continuous uniform distribution $H(e)$ which is defined over the interval interval $[0, E(x)]$. Thus, at any point in time, there is a mass $1/E(x)$ of potential new firms that may enter the market by purchasing k units of capital at cost e. As we will see below only those firms drawing relatively low costs, or good investment projects, will find it optimal to start producing.

Assuming that $H(e)$ is uniform allows us to use $E(x)$ to control the variation in average cost or efficiency of new projects available at any point in time. For instance if $E'(x) < 0$ there are more potentially good projects in good times. Although we

[10]Although we can readily construct other measures of credit spreads in the model we prefer this measure since empirically part of the spread between treasuries and corporate yields seems to be driven by liquidity and other microstructure issues that we ignore in this model.

restrict ourselves to studying a one-shock model driven solely by fluctuations in aggregate productivity it is also fairly immediate to have $E(\cdot)$ depend on an a separate, investment-sector shock, as in Greenwood, Hercowitz and Huffman (1988) or Fisher (2006) for example.

2.1.6 Optimal Capital Structure

Each individual firm finances their initial purchases of capital using a mix of debt and equity. This initial capital structure is chosen to maximize the expected total value of the firm (i.e. debt plus equity). Formally this optimal ex-ante value of the firm $A_0(s)$ is given by the expression:

$$A_0(s) = \max_{b \geq 0} \{ \int Q(s, z, b) + B(s, z, b) dG(z) \} \tag{10}$$

It follows from this that each potential entrant will enter the economy if and only if the setup cost e is less or equal the ex ante firm value $A_0(s)$. Formally then entry occurs whenever

$$e \leq \bar{e}(s) = A_0(s) \tag{11}$$

It is easy to show that the value of entry $A_0(s)$ rises with x) so that the entry cutoff $\bar{e}^2(s)$ will be strongly procyclical. This implies that the relatively costly projects are only adopted in good times. By contrast during recessions only low e projects are implemented. Below we show how optimal entry by individual firms determines the behavior of aggregate investment in equilibrium.

To summarize the optimal behavior of each individual firm is characterized by:

- The optimal entry cutoff, $\bar{e}(s)$, implied by condition (11),
- An optimal leverage choice, $b = \bar{b}(s)$ implied by (10), and
- An optimal default cutoff, $z = z_d(s, b)$, implied by (5).

These definitions make it clear however that all individual firm decisions will depend on the aggregate state of the economy, s. This state needs to be determined in general equilibrium and is the key difficulty in solving these classes of models.

2.2 Aggregation

To characterize the general equilibrium of the model we start by aggregating the optimal policies of each individual firm to construct aggregate quantities for our economy. We begin by defining $\mu_t(b, z)$ as the cross-sectional distribution of firms over leverage and idiosyncratic shocks. Since capital k is installed upon entry and does not vary afterwards all of firm heterogeneity is restricted to different choices of b and draws of z. We use the subscript t to emphasize that the distribution $\mu(\cdot)$ will also move over time according to the state of aggregate economy.

We construct aggregate output in this economy as follows:

$$\mathbf{Y}(s) = \int_{z_{d(s,b)}}^{\infty} xzk \, d\mu \tag{12}$$

Aggregate investment in the economy is given by the sum of the initial setup costs for the entering firms:[11]

$$\mathbf{I}(s) = \int_0^{\bar{e}(s)} ekdH(e) \ = \frac{\bar{e}^2(s)}{E(x)}k, \tag{13}$$

where we have used the fact that $H(e)$ is uniform.

This quadratic expression is similar to those obtained in simple aggregate macro models with ad-hoc adjustment costs. Moreover, because in equilibrium $\bar{e}^2(s)$ is pro-cyclical, aggregate investment in our model will behave much in the same way. As shown by several authors the costly transformation between consumption and capital goods is

[11]For simplicity in our model the behavior of aggregate investment is directly linked to new entry. This enhances tractability by ensuring that variation in firm capacity does not add to existing cross-sectional heterogeneity. However we could easily augment this by adding a required maintenance investment δk to incumbents as well.

another important element in generating sufficient variation in the price of financial assets in production economies[12]

As we have noted above allowing $E(x)$ to change over time introduces variation in the average quality of available projects. and will affect the volatility of investment expenditures over the business cycle. For example allowing for $E(x)$ to be countercyclical, so that more good projects are available in good times, implies that aggregate investment will respond more to underlying shocks.

An additional variable of interest is the deadweight losses associated with bankruptcy which is given by

$$\mathbf{BC}(s) = \int_0^{z_{d(s,b)}} \phi(1 + xz)k \, d\mu \tag{14}$$

Finally we can also construct the aggregate market value of corporate equity and debt respectively with the expressions:

$$\mathbf{V}(s) = k \int_{z_{d(s,b)}}^{\infty} Q(s, z, b) \, d\mu \tag{15}$$

and

$$\mathbf{B}(s) = k \int_{z_{d(s,b)}}^{\infty} B(s, z, b) \, d\mu \tag{16}$$

These definitions for the aggregate quantities allow us to identify the aggregate state of our economy s more specifically with the pair (x, μ). Intuitively this means that all aggregate quantities and prices will depend not only on the average state of productivity (or profits) but also on the cross-sectional variation in firm productivities and balance sheet positions.

[12] An early discussion is offered in Jermann (1997). For recent applications in similar settings see Kaltenbrunner and Lochstoer(2010) and Croce(2010). Our formulation here is closer to Gomes, Kogan and Zhang (2004).

2.3 Households

We now close our general equilibrium model by describing in detail the behavior and constraints faced by the households/investors. We assume that our economy is populated by a competitive representative agent household, that derives utility from the consumption flow of the single consumption good, C_t. This representative household maximizes the discounted value of future utility flows, defined through the Epstein-Zin (1991) and Weil (1990) recursive function:

$$U_t = \{(1-\beta)u(C_t)^{1-1/\sigma} + \beta\,\mathrm{E}_t[U_{t+1}^{1-\gamma}]^{1/\kappa}\}^{1/(1-1/\sigma)}. \tag{17}$$

The parameter $\beta \in (0,1)$ is the household's subjective discount factor and $\gamma > 0$ is the coefficient of relative risk aversion. The parameter $\sigma \geq 0$ denotes the elasticity of intertemporal substitution and $\kappa = (1-\gamma)/(1-1/\sigma)$.

Our household invests in shares of each existing firm as well as riskless bond which in zero net supply and earns a period rate of interest r_t. We also assume that there are no constraints on short sales or borrowing and that households receive the proceeds of corporate income taxes as a lump-sum rebate equal to:

$$\mathbf{T}(s) = \int_0^\infty \tau xzk\,d\mu \tag{18}$$

Given these assumptions the equilibrium stochastic discount factor for our economy between two adjacent periods is defined by the expression:

$$M_{t,t+1} \quad = \quad \left[\beta\left(\frac{C_{t+1}}{C_t}\right)^{-1/\sigma} R_{W,t+1}^{1-1/\kappa}\right]^{\kappa}. \tag{19}$$

where

$$R_{W,t+1} = \frac{W_{t+1} + C_{t+1}}{W_t}.$$

is the return on total household wealth, including bonds and tax proceeds.

As is well known, the absence of arbitrage implies that all gross asset returns in this economy will satisfy:

$$\mathrm{E}_t[M_{t+1}R_{i,t+1}] = 1, \tag{20}$$

for all assets i.

2.4 Equilibrium

We have shown how investor behavior determines the equilibrium stochastic discount factor, $M_{t,t+s}$, given household wealth. Earlier we described optimal firm behavior given the stochastic discount factor and shown how it determines aggregate investment and output as well as household wealth. Ensuring consistency between these two pieces of the economy requires that aggregate consumption by households is equal to aggregate production, net of investment and deadweight losses.

Formally our competitive equilibrium can then be constructed by imposing the additional consistency condition:

$$C_t = C(x, \mu) = \mathbf{Y}(x, \mu) - \mathbf{I}(x, \mu) - \mathbf{BC}(x, \mu) \tag{21}$$

This ensures that the stochastic discount factor used by each firm corresponds to that implied by optimal household behavior.

3 Computation

This section provides a brief description of our approach to solve the model in section 2 and our choice of parameter values. Although the model is relatively parsimonious the computation of the competitive equilibrium is difficult because the cross-section measure of firms $\mu(\cdot)$ changes over time.

3.1 Computation

Computing the competitive equilibrium requires the following three basic steps:

- Given an initial stochastic discount factor $M_{t,t+s}$ solve the problem of each individual firms and determine the optimal level of entry and default
- Aggregate individual firm decisions and use the consistency condition (21) to compute aggregate consumption and wealth
- Ensure that the implied aggregate quantities are consistent with the initial process for $M_{t,t+s}$.

Convergence of this procedure delivers the equilibrium values for all individual and aggregate quantities in the model. The appendix described this procedure in more detail.

3.2 Parameter Choices

Table 1 reports the parameters that we use for our benchmark numerical analysis. The preference parameters β, γ and σ are chosen to ensure that the model matches the key properties of the risk free rate and the aggregate equity premium in the economy.

Several studies have shown how to combine time non-separable preferences and persistent shocks to aggregate growth to produce these results. Our contribution here is simply to show how these dynamics can arise endogenously in general equilibrium. In fact parameter values are quite similar to several papers in this literature.[13]

To pin down the volatility and persistence of the aggregate productivity process we require that our model matches the volatility and persistence of output growth in the data. This implies that $\rho_x = 0.96$ and $\sigma_x = 0.01$. The parameters for idiosyncratic shocks determine the amount of cross-sectional variation in firm heterogeneity. Since

[13]For an early example of this approach and findings see Bansal and Yaron (2004). Lochstoer and Kaltenbrunner (2009) and Croce (2010) also show how production economies can generate these results.

we are especially concerned with the role of leverage and credit spreads in our economy we set these parameters to match the unconditional means of both of these variables. Thus we choose the value of $\rho_z = 0.94$ and $\sigma_z = 0.2$

As we have discussed earlier the upper bound on installation costs $E(x)$ is used to generate the appropriate volatility of aggregate investment. We do this by setting the elasticity of $E(x)$ with respect to x equal to -0.25.

Finally we also need to determine the value of the marginal corporate tax rate, τ and bankruptcy and issuance costs, ϕ and λ, respectively. Setting the marginal tax rate to 0.2 captures both the direct effects of corporate income taxes and those of individual taxes on distributions and interest. For an estimate of bankruptcy costs we turn to Warner (1977) who suggests that a value of about 0.3 reflects both the direct and indirect costs associated with this process. Finally we use 5% to denote the marginal cost of issue equity, an estimate that is similar to that used in Gomes (2001) and estimated in Hennessy and Whited (2006) and to popular measures of underwriting discounts in the US.

4 Findings

We are now ready to describe our quantitative findings. We begin by summarizing the basic properties of the model by reporting the unconditional means and volatilities of the major aggregate quantities and asset prices. We then examine the model's implications for the behavior of financial variables over the business cycle and compare those with the available empirical evidence. Finally we investigate the role of credit spreads in predicting future movements in both macro quantities and in equity markets.

To construct the statistics reported below we solve the model by numerical dynamic programming as detailed in 3. We then simulate the implied equilibrium policies at monthly frequency to construct 1000 independent panels of 59 years each. Macroeconomic data is aggregated at the quarterly frequency to match the available data. Unless otherwise noted we always report the relevant empirical moments for the sample period between 1951 and 2009.

4.1 Basic Properties

The first panel in Table 2 reports the volatility of the key macroeconomic variables as well as the share of investment in GDP. We can see that our parameter choices imply a very close match between the model and the data along these dimensions. Not only is the share of investment (and consumption) plausible but both variables also seem to exhibit as much variability as in the actual data.

The lower panel in Table 2 documents the implied properties of the model for the unconditional means and volatilities of the risk free rate and the equity premium. As we can see, our model does a good job in replicating these facts. Both the level of the risk free rate and the equity premium are very close to those observed in the data, and this match does not require the very large movements in the risk free rate often associated with habit preferences. This is because the persistent stochastic variation in growth rates generated by our model increases the household's precautionary savings thereby lowering equilibrium interest rates.

While Bansal and Yaron (2004) have shown that accounting for long run movements in consumption and dividends, combined with preferences for a early resolution of uncertainty, delivers realistic risk premia in an endowment economy setting, this has proved harder to implement in general equilibrium production economies (Kaltenbrunner and Lochstoer (2010), Campanale, Castro and Clementi (2009), Croce(2010)). This is because in a production economy, general equilibrium restrictions usually tie dividends very closely to consumption, while empirically, dividends are much more volatile than consumption.

Financial leverage (endogenously) breaks the tight link between dividends and consumption and renders dividends an order of magnitude more volatile. This allows us to generate a realistic amount of stock market volatility which is crucial in matching the aggregate equity premia. Importantly our model also matches the very slow moving patterns in leverage (Lemmon, Roberts and Zender (2008)) and the long run movements in aggregate dividends observed in the data (Bansal and Yaron (2004)).

4.2 Credit Market Statistics

Table 3 shows the basic properties of the key credit market statistics as well as its empirical counterparts. Unlike the previous table the statistics reported in Table 3 are all based on the average properties of the cross-sectional distribution of firms.

The Table shows that our model almost exactly matches the cross-sectional average market leverage (the ratio of book leverage to the value of market equity plus book leverage). Moreover the model also yields a realistic level of credit defaults in our model, and average credit spreads.

The observation of a low default rate given the substantial tax benefits to debt are often interpreted as evidence of under-leverage by firms. However our model is able to match the observed leverage ratios because firms anticipate having to make costly equity issues in times of low profits. As a result they will optimally choose lower leverage ratios ex ante.

As in recent work by Bhamra et al (2008) and Chen (2008), macroeconomic fluctuations are crucial for generating realistic levels of credit spreads. In our model however, these fluctuations are driven by the endogenous interplay between investment and financing decisions in equilibrium. Firms entering the economy in booms will anticipate high profits in the future, which they optimally shield from taxes by tilting their capital structure towards debt financing. When the economy slips into a recession however, default rates increase and incumbents' bonds quickly loose value while credit spreads increase.

4.3 Investment and Finance over the Business Cycle

Table 4 documents the cyclical behavior of several investment and financing variables by reporting their cross-correlations with GDP. The table shows that all variables have the correct cyclical behavior in our model although the implied correlations are sometimes higher than in the data. Intuitively this is because our benchmark model relies on a single source of aggregate uncertainty so that the innovations in aggregate GDP growth are completely tied to those in aggregate productivity. As a result most of our results in Table 4 can be understood by examining the effects of aggregate productivity of the various variables.

Intuitively the persistence in the aggregate shocks implies a strongly pro-cyclical behavior in aggregate investment as new firms enter the market and build up productive capacity in anticipation of higher future profits. As a result the market value of firms (and especially of equity) is also strongly pro-cyclical implying a countercyclical pattern in market leverage.

Also intuitive is the behavior of both default rates and credit spreads which are strongly countercyclical since default is becomes less attractive when profits are temporarily high. As a result of this improvement in credit market conditions which leads book leverage will rise. This is because new entrants will choose a typically higher level of debt thus raising average leverage in the economy.

As in the data, firms are more likely to issue equity during good times in the model. Two effects are at work here, and they work in opposite directions. In the model firms issue equity at entry to finance investment in productive capacity and later on they need to secure additional funds in times of low profits in order to cover coupon expenses. This later effect leads to countercyclical issues but quantitatively it is not very strong. Anticipating that issuing equity is particularly costly in bad times, firms shift their initial capital structure towards equity when entering the economy, which is more likely to happen in times of high profits, thus rendering aggregate equity issuances procyclical.

4.4 Amplification of Underlying Shocks

Figures 5-5 look at the impact of fluctuations in credit markets on key macroeconomic quantities. Figure 5 directly compares the response to exogenous shocks in our benchmark economy with levered firms, to the response in an alternative environment where all firms are financed with equity alone. We find that economic fluctuations are more pronounced with output, consumption and investment growth all responding between 35% to 50% more to an increase in the level of aggregate productivity.[14] Intuitively as the risk of default drops debt becomes very cheap allowing firms to increase their ex-ante value considerably by exploiting the available tax shields. This encourages firm creation and investment spending.

Figure 5 illustrates the asymmetries in business cycle fluctuations with negative shocks producing sharper declines in output and investment. While a positive shock to productivity raises GDP growth about 1.2% above its mean, a negative shock of the same magnitude will reduce GDP growth by about 1.7%. Although documented by several authors this pronounced asymmetry in economic fluctuations is rarely obtained in macroeconomic models.

Intuitively a negative shock has two effects. First, it directly lowers output by

[14] The all-equity economy is constructed by examining the case where optimal leverage is 0 because there is no tax incentive to use debt.

lowering productivity and increasing default rates among incumbent firms. Second, widening credit spreads make debt expensive reducing the value of potential entrants and lowering investment spending. It is this second effect that is responsible for the asymmetric cycles. Because bond losses are concentrated in recessions credit risk raises sharply and credit spreads are much more sharply countercyclical here than in macro models relying on (effectively) risk-neutral investors.

Variation in risk premium matters for another reason. Because bankruptcy procedures are costly, investment is only partially reversible. This generates countercyclical variation in consumption growth and adds to the market price of risk in recessions and the variation in equilibrium credit spreads.

Figure 5 compares a typical recession with one that starts from a position of "debt overhang" where firms are artificially endowed with excessive amounts of leverage.[15] Although somewhat arbitrary this experiment is an effective way to capture the possible aftermath of a "over-leverage" crisis like the one in 2008-09. Figure 5 shows how much deeper and more persistent this second recession would be in our model. Over-leverage would make GDP fall by another 0.5% per quarter and reduce investment growth by almost 2%.

4.5 Credit Market Shocks

Although we have focused only on technology driven fluctuations our model can readily accommodate several other types of shocks. In this section we show how to modify our benchmark formulation to capture the idea of an exogenous shock to "credit market

[15] Formally we compare average recessions generated by a one standard deviation negative shock to x. In the first case all firms start with the optimal amount of leverage implied by their policy rules. In the second case we endow firms with the optimal amount of leverage implied by setting x one standard deviation above its mean.

conditions". We can do this by assuming that the recovery rates in bankruptcy fluctuate over time, perhaps as a result of shocks to liquidation values or "liquidity".[16] Equation (6) shows that fluctuations in the recovery rate, ϕ, directly affect the relative price of credit to the firm so that we can also think of these liquidity shocks as simply credit market shocks.

Formally we now assume that ϕ can take two values: a benchmark value of 0.25 which we think approximates average bankruptcy costs and an extreme (but rare) value of 0.75 that occurs during liquidity crisis. We also assume that ϕ evolves over time according to a two-state Markov chain with the following transition probabilities:

$$P[\phi_{t+1} = 0.25 | \phi_t = 0.25] = 0.98, \tag{22}$$

$$P[\phi_{t+1} = 0.75 | \phi_t = 0.75] = 0.5, \tag{23}$$

In practice this means that liquidity crisis are both rare and temporary.

Figure 5 shows the average response of output and investment to an unexpected tightening of credit conditions. This shock has several effects. First they devalue outstanding bonds and reduce household wealth. In general equilibrium this leads to a decline in equity values and increases corporate defaults. Hence output falls. This is an effect on incumbent firms. On the other hand higher bankruptcy costs makes debt significantly less attractive for potential entrants. Therefore the average ex ante firm value falls and less firms break even in expectation. This leads to less entry and less investment.

Comparing with the response to a standard technology shock however we see that a credit shock has a significantly larger impact on investment relative to output. Sensibly in our model fluctuations in credit conditions impact young (and small) firms much more than the older established ones. Again this is novel feature relative to many aggregate

[16]Einsfelt and Rampini (2007) suggest that these types of shocks can be important to explain measured variation in individual firm investment over time.

macro models that rely on borrowing constraints that affect all firms equally.

4.6 Credit Spreads and Business Cycle Predictability

Finally we examine the ability of credit markets, and in particular credit spreads, in forecasting movements in the aggregate economy. Tables 5 and 6 show the results of regressing the k period ahead growth in (log) output and investment, respectively, on the value weighted aggregate credit spread at time t. They show that credit spreads in our model are able to forecast movements in both aggregate output and investment at horizons ranging between 1 quarter and 1 year. This finding is consistent with much empirical evidence about the forecasting ability of credit spreads and documented recently in Mueller (2008), Gilchrist et al (2008) and Lettau and Ludvigson (2004).

In both the data and the model the forecasts are both statistically and economically meaningful. Moreover the estimated coefficients on the simulated panels are of very similar magnitudes to those found in recent empirical studies.

The intuition for these results follows from the fact that the cyclical nature of consumption implies that investors will incur larger losses on defaulted bonds in recessions, precisely when marginal utility is high giving rise to sharply countercyclical credit spreads.

As a consequence firms find it especially costly to obtain debt financing during recessions. In our model, this makes it difficult for the young (new) firms to obtain funding for investment expenditures and depresses aggregate investment and output for a number of quarters thereafter. Risk premia in corporate bond markets are thus propagated into the real economy and this accounts for the predictive power of credit spreads for output and investment. Moreover these endogenous movements in risk premia also play a key role in amplifying underlying macroeconomic conditions. Thus credit risk premium emerges as the common link between credit markets, equity markets and macroeconomic aggregates.

5 Conclusion

In this paper we propose a tractable general equilibrium asset pricing model with heterogeneous firms that links movements in stock and bond markets to macroeconomic activity. The model endogenously links movements in aggregate quantities such as investment and output to the prices of stocks and bonds. As a result movements in financial variables such as credit spreads and expected equity returns will forecast future economic activity. In our model these movements are largely driven by risk premia. In our equilibrium setting, endogenous default increases the volatility of consumption during recessions, thereby rendering the market price of risk sharply countercyclical. As a consequence, expected returns on stocks are higher in recessions, which are naturally anticipated by movements in credit spreads. Endogenous movements in credit markets allow our model to match the observed conditional and unconditional movements in stock market returns and credit spreads with a reasonable amount of aggregate volatility.

While a long theoretical literature in macroeconomics has demonstrated that financial frictions have the potential to deliver a powerful amplification mechanism for macroeconomic shocks, our mechanism here is quite distinct. Classical papers in this literature (e.g. Kyotaki and Moore (1997), Bernanke, Gertler, Gilchrist (1999), Cooley, Marimon and Quadrini (2004) and others) often emphasize the agency problems arising between investors and small entrepreneurial firms and focus on how changes in aggregate economic conditions exacerbate these frictions. Almost all of them however rely on sharp movements in default frequencies in risk neutral settings almost always generating sharply counterfactual properties for asset prices.

In contrast, in our model shocks are amplified through endogenous movements in credit risk premia that affects all corporations equally. As a result we can reconcile the core features of a business cycle contraction with the key properties of equity and credit markets. Our approach then seems to offer a more plausible mechanism for the role of financial markets in the propagation of the underlying shocks.

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Appendix: Computation Details

The computation of the competitive equilibrium is complicated by the endogeneity of the pricing kernel, which embodies the equilibrium market clearing conditions. The main difficulty of course is the dependence of all aggregate quantities on the cross-sectional distribution, μ, which is a high-dimensional object.

Our solution algorithm exploits two basic techniques to overcome these obstacles. First, we re-normalize the value functions for debt and equity to express them in units of marginal utility which is computationally more convenient. Next, following Krusell and Smith (1998), the cross-sectional distribution μ is approximated by a low-dimensional state variable that summarizes the relevant information in μ.

The expression for the pricing kernel (19) guides both our choice of the approximate state space and the re-normalizations. To that end, we define the function:

$$p(C, W) = C^{-\frac{\kappa}{\sigma}} W^{\kappa - 1}$$

and rewrite the expression for the market-to-book value of equity as

$$\hat{Q}(s, z, b) \quad = \quad Q(s, z, b) p(C, W)$$

In an analogous way we can define $\hat{B}(s, z, b)$ as the normalized market value of debt (relative to capital).

In the next step, we approximate the high-dimensional state space $s = (x, \mu)$ by $\hat{s} \equiv (x, W)$. In other words, we assume that aggregate household wealth W captures all the relevant information about aggregate quantities contained in the cross-sectional distribution μ.

We can then write

$$\begin{aligned}\hat{\hat{Q}}(x,W,z,b) &= \hat{Q}(\hat{s},z,b)\\ &= \max\{0,(1-\tau)(1-\lambda)(xz-b)p(\hat{C}(x,W),W)\\ &\quad +E\left[\beta^{\kappa}\left(\frac{W'+\hat{C}(x',W')}{\hat{C}(x,W)}\right)^{\kappa-1}\hat{\hat{Q}}(x',W',z',b)\right]\}\end{aligned}$$

where $\hat{C}(x,W) = C(\hat{s})$ in our approximate state space. $\hat{\hat{B}}(x,W,z,b)$ is also defined analogously.

Our numerical strategy is based on numerically iterating on the functional equations $\hat{\hat{Q}}$ and $\hat{\hat{B}}$. To that end, we parameterize the consumption function $\hat{C}$ and the law of motion for aggregate wealth W' as log linear functions of the aggregate state, x and W:

$$\begin{aligned}\log C &= \alpha_0 + \alpha_1 \log x + \alpha_2 \log W\\ \log W' &= \eta_0 + \eta_1 \log x + \eta_2 \log W\end{aligned}$$

for some coefficient vectors α and η.

Following Krusell and Smith (1998), we guess an initial set of coefficients for these rules, and find the equilibrium rules by means of simulation. More precisely, we use the following procedure:

- Discretize the state space by choosing discrete grids for b and W, and the shocks x and z. Because the stochastic processes in our calibration are highly persistent, we discretize the shocks using the procedure detailed in Rouwenhorst (1995).

- Guess initial vectors α^0 and η^0

- Using these guesses iterate on the functional equations for $\hat{\hat{V}}$ and $\hat{\hat{B}}$. This yields the optimal decision rules for investment, default and optimal capital structure.

- Simulate the optimal decisions rules and compute the implied general equilibrium allocations for C and W.

- Use the implied time series for x, C and W to update the approximate log linear rules for C and W' and check the goodness of fit.

- Iterate until convergence.

For our simulation procedure we represent the distribution of firms at any time with a matrix $M_{t,ij}$, where M_t is $nz \times nb$. Here nz is the number of grid points in the discretization of z, and nb is the number of different values of coupons b that entering firms choose. Note that b is a function of both x and wealth W, so that in principle $nb = \infty$ as W is a continuous variable. We choose a finite number of grid points for b that approximate actual continuous choices sufficiently well. That implies $nb = nx \times nw$, where nw is the number of suitably chosen grid points for W. Each element m_{ij} of M_t represents the mass of firms with coupon b_j which drew idiosyncratic shock z_i at time t. We are interested in the evolution of M_t over time, that is, in the mapping of M_t into M_{t+1}.

M_t is the end-of-period t distribution, with which the economy enters into period $t+1$. We first need to account for default. For each aggregate state $s = (x, w)$ the default decision can be characterized by a $nz \times nb$ matrix D with elements 1 if firms with coupon b_j and shock z_i survive, and 0 firms with coupon b_j and shock z_i default. Aggregating over aggregate states this can be summarized with a three-dimensional array Df which is $ns \times nz \times nb$ where $ns = nx \times nw = nb$ is the number if discrete aggregate states. The distribution of surviving firms is then given by

$$\tilde{M}_{t+1} = M_t. \times Df(s_{t+1}, :, :)$$

where $.\times$ denotes element-by-element multiplication. Next we consider the transition between idiosyncratic states. Note that existing firms only 'move' within the same column $\tilde{M}_{t+1}(:, j)$ as their coupon b_j is fixed. With Markov transition matrix Tz the new distribution of surviving firms over idiosyncratic states is therefore given by

$$\tilde{\tilde{M}}_{t+1} = Tz \times \tilde{M}_{t+1}$$

Now we need to consider entering firms. Their mass $m_{e,t+1}$ is determined in equilibrium. They draw their idiosyncratic shock realizations from the ergodic distribution of z. They can be represented with a matrix N_{t+1}, with a non-zero column $n_{t+1} = N_{t+1}(:,l) = m_{e,t+1}T_e$ if the aggregate state at time $t+1$ is l where T_e represents the ergodic distribution of z, and zeros otherwise. The new end-of-period distribution is then

$$M_{t+1} = \tilde{\tilde{M}}_{t+1} + N_{t+1}$$

Table 1: **Calibration**

Parameter	**Values**
β	0.995
γ	10
σ	2
τ	0.2
λ	0.05
ϕ	0.3
ρ_x	0.96
σ_x	0.01
ρ_z	0.94
σ_z	0.2

This table reports parameter choices for our model. The model is calibrated at quarterly frequency to match data both at the macro level and in the cross-section. The implied moments are reported in table 2.

Table 2: **Aggregate Moments**

Variable	Data	Model
Macro Moments		
$\sigma[\Delta_C]$	1.45	1.49
$\frac{\sigma[\Delta_C]}{\sigma[\Delta_Y]}$	0.66	0.62
$\frac{\sigma[\Delta_I]}{\sigma[\Delta_Y]}$	4.30	3.42
$\frac{I}{Y}$	0.16	0.21
Asset Pricing Moments		
$E[r^f]$	1.69	1.26
$\sigma[r^f]$	2.21	1.45
$E[r^e - r^f]$	4.29	4.12
$\sigma[r^e]$	17.79	10.07

This table reports unconditional sample first and second moments generated from the simulated data of some key variables of the model. The model is simulated 1000 times over 63 years. All data are annualized. The return on equity refers to the value weighted aggregate stock market return. The corresponding parameter values used in the simulation are reported in table 2. The data are taken from Gomes, Kogan and Yogo (2008).

Table 3: **Credit Market Statistics**

Variable	Data	Model
Default rate	1.48	1.63
Credit Spread (10yr BAA-AAA)	0.95	0.99
Market Leverage	0.35	0.36

This table reports statistics related to credit markets and firms' capital structures. The model is simulated 1000 times over 63 years. All data are annualized. The default rate is from Jermann and Yue (2007), the credit spread and leverage ratio is from Chen, Collin-Dufresne and Goldstein (2008).

Table 4: **Financing Over Business Cycle**

Correlation w/ GDP growth	Data	Model
Investment	0.91	0.74
Market leverage	−0.11	-0.54
Equity Issuance	0.10	0.26
Credit Spread	−0.36	-0.71
Default rate	−0.33	-0.83

This table reports business cycle properties of key financial variables in the model. The model is simulated 1000 times over 63 years. All data are annualized.

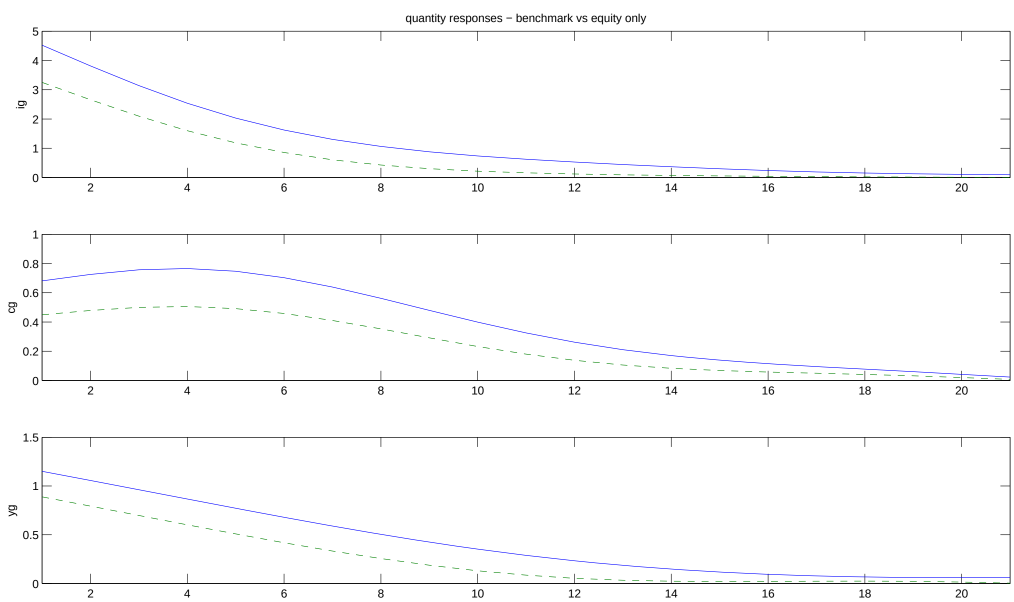

Figure 1. Business Cycle Amplification. This figure shows the response of consumption, investment and output growth, respectively cg, ig and yg, to a one standard deviation positive innovation in aggregate technology.

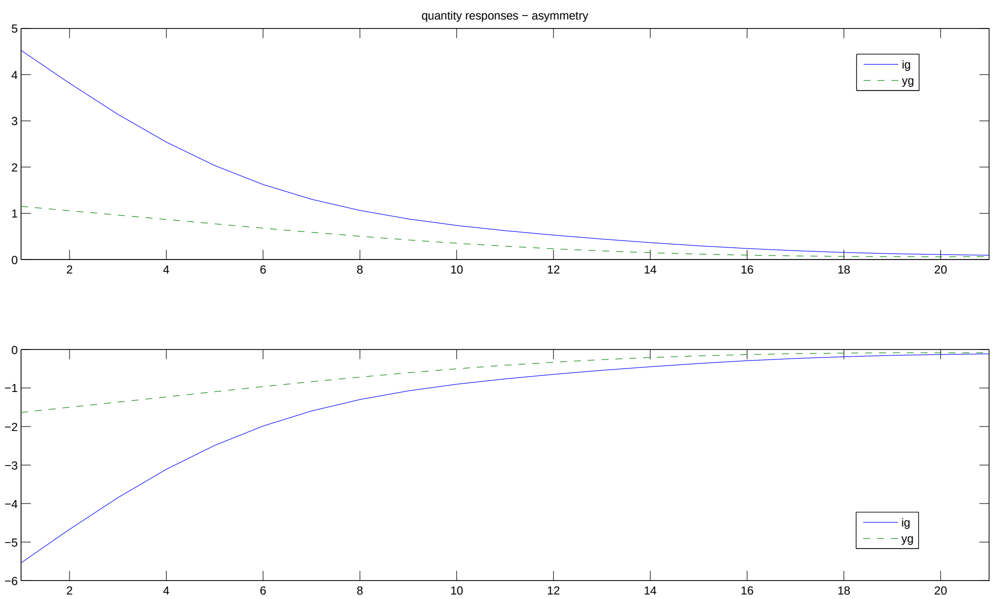

Figure 2. Booms and Busts. This figure compares the response of investment and output growth, respectively ig and yg, to positive and negative (one standard deviation) innovations in aggregate technology.

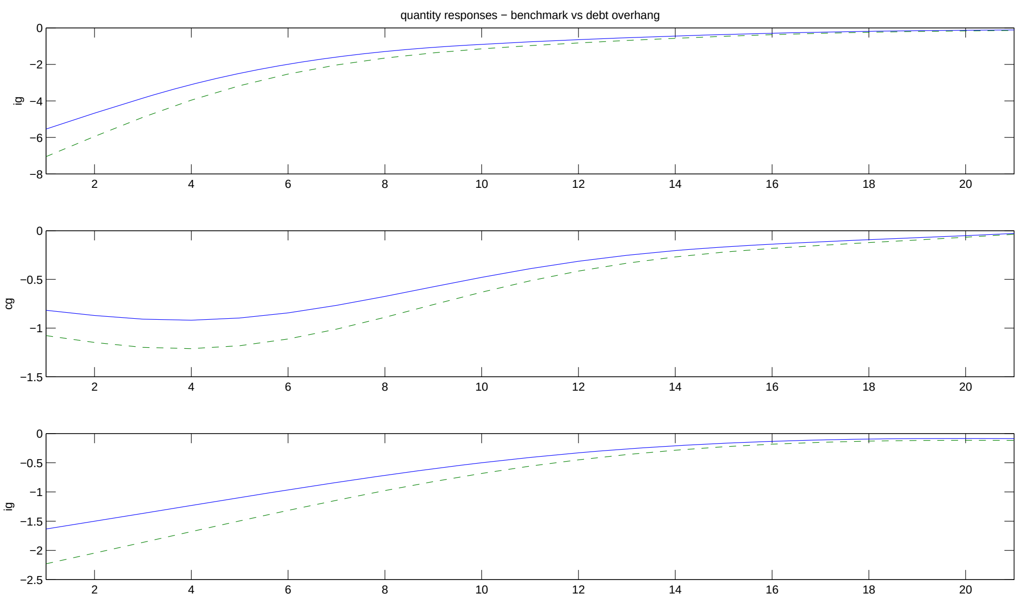

Figure 3. A Bust with Debt Overhang. This figure compares the benchmark response of consumption, investment and output growth, respectively cg, ig and yg, to a positive one standard deviation innovations in aggregate technology with the response in a world where firms have accumulated excessive debt.

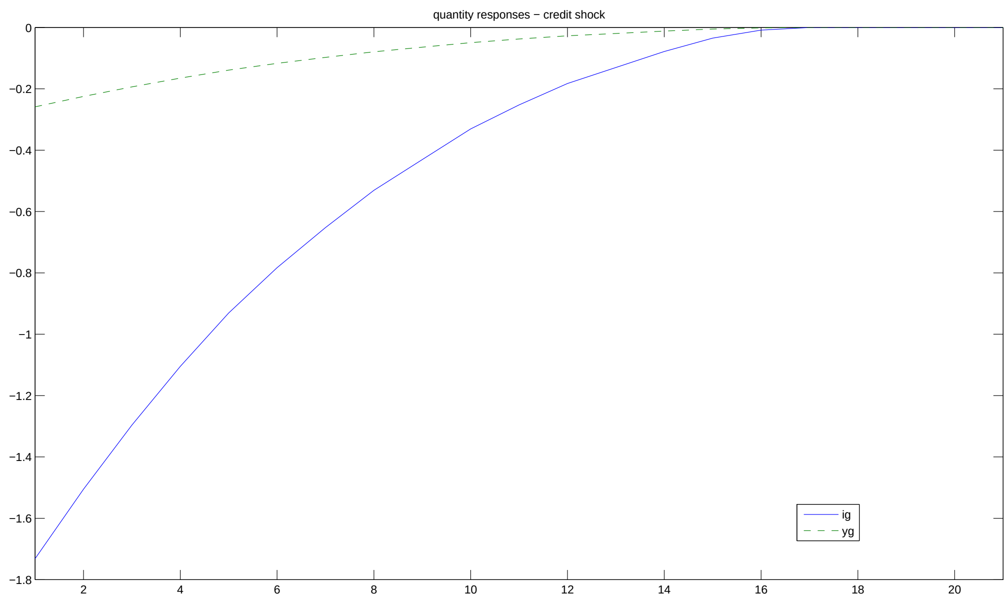

Figure 4. A Credit Market Shock. This figure shows the response of investment and output growth, respectively ig and yg, to a deterioration in credit market conditions.

Table 5: **Forecasting Output Growth**

$\Delta Y_{t,t+k}$	Actual Data		
Horizon k	1 quarter	2 quarter	1 year
CS_t	-1.20 (-4.26)	-2.24 (-3.58)	-3.89 (-2.82)
$\Delta Y_{t,t+k}$	Simulated Data		
Horizon k	1 quarter	2 quarter	1 year
CS_t	-1.69 (-2.41)	-2.19 (-2.28)	-2.85 (-2.15)

This table reports forecasting regressions for output growth. It regresses the k period ahead output log growth $\Delta Y_{t,t+k} = \log Y_{t+k} - \log Y_t$ on the value weighted aggregate credit spread at time t, CS_t. T-statistics are reported in parentheses below. These numbers are obtained by averaging the results from simulating the economy 1000 times over 63 years. The standard errors are corrected using Newey-West with 8 lags.

Table 6: **Forecasting Investment Growth**

$\Delta I_{t,t+k}$	Actual Data		
Horizon k	1 quarter	2 quarter	1 year
CS_t	-3.69	-6.54	-9.71
	(-4.30)	(-3.16)	(-2.39)
$\Delta I_{t,t+k}$	Simulated Data		
Horizon k	1 quarter	2 quarter	1 year
CS_t	-2.92	-5.73	-7.96
	(-2.32)	(-2.21)	(-2.07)

This table reports forecasting regressions for investment growth. It regresses the k period ahead investment growth $\Delta I_{t,t+k} = \log I_{t+k} - \log I_t$ on the value weighted aggregate credit spread at time t, CS_t. T-statistics are reported in parentheses below. These numbers are obtained by averaging the results from simulating the economy 1000 times over 63 years. The standard errors are corrected using Newey-West with 8 lags.