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MONETARY POLICY AND THE FINANCIAL DECISIONS OF FIRMS

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Monetary Policy and The Financial Decisions of Firms*

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Abstract

In this paper we develop a general equilibrium model with heterogeneous, long-lived firms where financial factors play an important role in production and investment decisions. The model generates firm dynamics in which the production and investment behavior of small and large firms differs substantially and responds differently to monetary shocks. We find that small firms are more sensitive to monetary shocks than big firms, and the response of the economy to monetary shocks is characterized by greater persistence than is typically found in other monetary business cycle models. We also find that monetary policy shocks have only a small impact on aggregate output but lead to considerable volatility in financial markets, particularly in stock market returns.

Introduction

Empirical studies of the financial decisions of firms have documented important differences in the behavior of large and small firms. It has been shown by Fazzari, Hubbard, & Petersen (1988) and others that small firms are more profitable, pay fewer dividends, take on more debt, invest more. Recent studies by Gertler & Gilchrist (1994), Gilchrist & Himmelberg (1994) and Gilchrist & Himmelberg (1998) have also shown that the investment of small firms is more sensitive to cash flows and they respond to monetary policy shocks very differently than do large firms. Because many of these authors identify small firms as *a priori* more likely to face financial constraints, these empirical features are widely interpreted as indirect evidence of frictions in financial markets. These frictions are then conjectured to be an important channel in the propagation of monetary policy shocks, referred to as the "credit channel of monetary transmission".[1] Quantitative studies of the credit channel of monetary transmission by Fuerst (1995) and Fisher (1996) have so far concluded that it is quantitatively unimportant.

In this paper we argue that the many differences in behavior of large and small firms have a common explanation. It is that the financial decisions of firms will differ systematically with the amount of equity in the firm. We study the financial decisions of firms that are heterogeneous in the amount of equity capital embodied in their business. The capital structure

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[1]See Bernanke & Gertler (1995) for a review.

of firms changes endogenously over time as a result of their financial decisions and in response to idiosyncratic shocks to technology. The model is in the spirit of models by Jovanovic (1982) and Hopenhayn (1992), in that shocks cause firms to enter and exit. The key difference is that, in this environment, financial decisions play the central role.[2]

We describe an artificial economy where all firms have access to the same technology for producing a single good, with labor and capital inputs. The firm's production plan is financed with cash borrowed from a financial intermediary. Firm equity is used as collateral for loan contracts that the firms sign with the bank. The cost of the loan depends on the probability that the firm will not be able to repay the debt, which in turn depends on the amount of equity in the firm. If the firm is not able to repay the debt, it defaults. Consequently, firms face a trade-off in deciding the optimal amount of debt: on the one hand, more debt allows them to expand production and to increase their expected profits; on the other hand, the increase in the amount of debt implies a higher probability of failure. This trade-off induces firms to behave differently depending on the amount of equity they have in their business. One implication is that firms with less equity will choose smaller production plans.

Firm financing and investment decisions determine how firms grow over time. Accordingly, any successful treatment of the financing decisions of heterogeneous firms should be consistent with an important set of observations about industry dynamics. Studies of the relationship between firm size and growth have overturned the conclusion of Gibrat's Law which holds that firm size and growth are independent. Studies by Hall (1987) and Evans (1987), for example, show that the growth rate of manufacturing firms and their volatility is negatively associated with firms age and size, and the survival rate is increasing in age and size. Davis, Haltiwanger, & Schuh (1996) find that the rates of job reallocation are decreasing in the firm size and age. In Cooley & Quadrini (1997) we establish that the environment studied in this paper reproduces many of the salient features of industry dynamics that are observed in U.S. data. In particular, smaller and younger firms grow faster, they experience greater variability in their growth rates, higher rates of job reallocation, and they face a smaller probability of surviving. In that paper we also describe the mechanism that generates these industry dynamics.

In addition to replicating the observed features of industry dynamics, the model economy developed in this paper provides some insight on the importance of firm heterogeneity as a channel of transmission for monetary policy. We find that there are important differences in the response of large and small firms to monetary shocks. In particular we find that the response of small firms to monetary shocks is much greater than that of large firms. Firm heterogeneity also generates more persistence in the response of the economy to monetary shocks. Nevertheless, we find that the aggregate real effects of monetary shocks are very small.

The explicit treatment of the financial decisions of firms highlights some important consequences of the liquidity effect of monetary shocks. Although we find that monetary shocks have only a marginal impact on output fluctuations—a finding consistent with the results of Sims (1992) and Leeper, Sims, & Zha (1996)—they significantly affect the stock market return and they have a large impact on the volatility of stock returns. The latter finding is consistent with a variety of empirical evidence.[3] In addition, the model generates fluctuations in stock

[2]Gomes (1997) studies a similar environment in which firm heterogeneity and financial decisions are central to understanding the behavior of firms investment behavior.

[3]Thorbecke (1997) and Hinkelman (1997) for example find that monetary policy has a significant effect on the

market returns that are far greater than the fluctuations of dividends, output and returns from direct real investment of households. This excess volatility of stock returns has been regarded as a puzzle for representative agent economies (LeRoy (1989), Shiller (1981)). Thus, monetary shocks have a far greater impact on financial markets than their impact on the real economy would seem to warrant. It is important to emphasize that all the reactions reported occur solely as a consequence of optimizing behavior on the part of households, firms, and financial intermediaries.

In the next section we describe the model economy to be studied and the decision problems facing households, firms, and financial intermediaries. We then describe the problem of the firm and the households in some detail and define the competitive equilibrium for this economy. After describing the calibration of the model, we present the properties of the artificial economy. These show that the financial decisions of heterogeneous firms help to understand why firms of different size behave differently over time and over the business cycle.

1 The Model Economy

The economy consists of three types of agents: households, financial intermediaries and firms. Financial intermediaries intermediate liquid assets (money) between households and firms. Shares of the financial intermediaries and firms are owned by the households.

Households

The economy is populated by a continuum of homogeneous households of total measure 1, that maximize the expected lifetime utility:

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

where c_t and l_t are consumption and labor at time t, and β is the households's intertemporal discount factor.[4] The utility function satisfies the standard properties. The household is endowed with one unit of working time that can be supplied to the market in return for the real wage rate w. Household assets are of four types: cash, deposits, rental capital and firm shares.

Households hold money for transactions purposes. Cash is required for purchases of consumption, investment goods and shares of new firms. At the end of the period, each household holds an amount m of liquid assets (money). An amount d is deposited with a financial intermediary (bank) and earns the nominal interest rate r_d. The amount $m - d$ is available for transactions in the next period. A crucial assumption is that the stock of deposits cannot be changed before the end of the next period. This is the assumption typically made in the class of monetary models usually referred to as "limited participation" models. At the beginning of the next period, the household observes the aggregate shocks, and it decides on its labor supply l, the supply of rental capital to the firms k_h, consumption c, gross investment in rental capital i_h and subscription of new firms' shares.

stock market and Shanken (1990) shows that it affects the betas of portfolios of firms.

[4]Throughout we use small letters to denote individual state and choice variables and prices, while capital letters denote aggregate variables.

Define μ^n to be the portfolio of new firms' shares purchased by the household. The portfolio is a measure over the number of shares for each type of firm, where the firm's type will be specified below. Moreover, denote by $q^n(\mu^n)$ the real market price of that portfolio. The households' cash-in-advance constraint is given by:

$$p(c + i_h + q^n(\mu^n)) \leq m - d + pwl + pr_k k_h \tag{2}$$

where r_k is the real rental rate of capital and p is the nominal price level.

According to equation (2), the total cash available to households derives from three sources: previous holdings $m - d$, labor income, pwl, and payments of rents, $pr_k k_h$. This cash can be used to purchase consumption goods, investment goods and shares of new firms. As we will see, new firms requires an initial investment which is sunk (fix cost) and they are endowed with an initial stock of capital (variable cost). We assume these initial costs require cash and this cash is obtained by selling the shares of the new created firms to the households. In equilibrium, the market price of the shares of a new firm is equal to its set up costs. The assumption that new firms' investment, as well as the households' investment in rental capital, need to be paid with cash, is important to generate the liquidity effect of monetary shocks.[5]

At the end of each period, the household receives the repayment of the bank deposits, inclusive of the interests, and dividend payments from the firms and the financial intermediaries. Moreover, they also trade in the shares of existing firms (old firms). Therefore, while the purchases of new firms' shares (primary market) take place at the beginning of the period with cash, transactions in existing firms' shares (secondary market) take place at the end of the period. Define μ to be the initial portfolio of old firms' shares and μ^o the net purchases of the existing firms. The real market price of this portfolio is denoted by $q(\mu^o)$. The household's end-of-period money holding (assuming that the cash-in-advance constraint holds with equality) is:

$$m' = d(1 + r_d) + p\pi(\mu) - pq(\mu^o) \tag{3}$$

where $\pi(\mu)$ are the (real) dividends paid to the owner of the portfolio of old firms' shares μ.[6] The end-of-period stock of money m' is allocated to cash holding and deposits before the beginning of the next period.

The evolution of the household's stock of rental capital is given by $k_h' = (1 - \delta)k_h + i_h$, where δ is the depreciation rate, and the evolution of the portfolio of firms' shares is given by the function $\mu' = \psi(\mu, \mu^o, \mu^n)$. The precise nature of this function will be specified below after the description of the firms.

Financial intermediaries

In this economy there is a continuum of competitive financial intermediaries. At the end of each period, the financial intermediaries collect deposits from households, and use these funds to make loans to firms at the beginning of the next period. They also receive injections of liquid funds from the monetary authority. The growth rate of money, denoted by g, is a stochastic

[5]Christiano (1991) shows that in the standard limited participation model in which investment does not enter the cash-in-advance constraint, monetary policy shocks do not necessarily have liquidity effects. However, by assuming that at least part of the investment enters the cash-in-advance constraint, the model developed in this paper is able to generate the liquidity effect of monetary shocks.

[6]Only old firms pay dividends in the current period. New firms start paying dividends in the next period.

process that takes place at the beginning of each period. The sum of deposits and monetary injection represents the total amount of loanable funds. These funds are lent to firms through a standard one period contract based on a non contingent interest rate. The interest rate charged to each loan, denoted by $\tilde{r}_l$, depends on the firms' probability of failure. If the firm does not fail, the intermediary gets back the loan plus interest at the end of the period. If the firm fails, the intermediary gets the realized value from the liquidation of the firm. The charged interest rate is such that the intermediary expects to earn on average a rate r_l from each loan. The firm-specific interest rate $\tilde{r}_l$ is implicitly defined by the following equation:

$$(1 + r_l)b = (1 + \tilde{r}_l)b \cdot prob(\text{no-default}) + E(V_{res}|\text{default}) \cdot prob(\text{default}) \tag{4}$$

where b is the firm's nominal debt and V_{res} is the nominal liquidation value of the firm in the event of default. Because the intermediaries pool a large number of loans, the return from the lending activity is known and their role is essentially to provide insurance. The risk-free lending rate r_l is determined so that the demand for loans from the firms is equal to total supply of loanable funds.

The intermediation sector is competitive, and therefore, in equilibrium intermediaries do not make any profits. This implies that the interest on loans r_d paid to the households is implicitly determined by the following zero-profit condition:

$$(1 + r_d)D = (D + \Delta M)(1 + r_l) \tag{5}$$

where D is the aggregate stock of deposits and $\Delta M = gM$ is the aggregate injection of money.

Our financial intermediation sector is slightly different than in other limited participation models as for example in Christiano & Eichenbaum (1995). We assume that the monetary authority makes monetary transfers directly to the intermediaries and the intermediaries can use these transfers to remunerate the depositors, or to make extra loans. In other limited participation models, the monetary authority makes transfers to the households. However, these transfers are in the form of deposits and the households have to wait until next period to use these funds for transactions. One implication of our assumption is that, if the growth rate of money is positive, the interest rate on loans is smaller than the interest rate on deposits.[7] As we will see, this feature of the model is important in affecting the types of assets that firms decide to accumulate.

Firms

In this section we describe the characteristics of existing (old) firms, that is, firms that were created in previous periods and survived to the current one. The description of new firms is deferred to section 2.3 which analyzes the problem faced by new entrant firms.

[7]This feature of the model is clearly incompatible with the data where the interest on loans is greater than the interest on deposits. However, the purpose of the paper is not to explain the return structure of different investments available in the economy but rather their cyclical properties. So, for example, although the model does not solve the well known equity premium puzzle, it generates a negative and persistent fall in the lending rate after a positive monetary policy shock that several empirical studies have shown to be an empirical regularity of the data (liquidity effect). See, for example, Christiano, Eichenbaum, & Evans (1996), Hamilton (1997), Leeper et al. (1996).

At each point in time there is a continuum of firms that have access to the decreasing return-to-scale technology:

$$y = z\,\varphi\,F(k,l) = z\,\varphi\,(k^{\theta}l^{1-\theta})^{\nu} \tag{6}$$

where z is an aggregate shock, φ is an idiosyncratic shock to technology, k is the input of capital and l is the input of labor. The shock φ is assumed to be independently and identically distributed on the real line.

At each point in time, firms are characterized by the amount of capital, e, that they own. Henceforth, this capital is referred to as the *equity*. The amount of equity changes over time as firms reinvest profits. The value of a firm will thus depend on the realizations of the idiosyncratic shock and its dividend policy. To keep the problem tractable, we assume that retained earnings is the only source of increased equity for the firm. We motivate this assumption by the observation that firms mainly rely on internal sources of funds for finance.[8]

In each period the firm hires labor and rents capital in addition to the capital they already own from households. Wages and capital rents have to be financed in advance and the firm obtains this working capital by borrowing it from a financial intermediary. Accordingly, the firm faces the constraint:

$$b \geq pwl + pr_k(k - e) \tag{7}$$

where b is the nominal value of working capital borrowed from the financial intermediary. This is the firm's short term debt.

The contract signed between the firm and the bank is a standard one-period debt contract based on a non-contingent interest rate. As long as the firm is able to repay the loan, the interest rate does not depend on the output realization. If the output realization is such that the firm is not able to repay the loan, inclusive of the interest, the firm defaults and the bank gets the liquidation value of the firm. The interest rate charged by the intermediary internalizes the probability of default of the firm and the liquidation value of its assets in the event of default as defined by equation (4).

The total amount of funds the firm can borrow is subject to an upper bound (borrowing limit). We assume that this limit is equal to the liquidation value of the capital owned by the firm (equity). Although the imposition of an exogenous borrowing limit may seem arbitrary, it can be justified by an enforceability argument similar to Albuquerque & Hopenhayn (1997).[9] If we justify this limit by an enforceability argument, where a value of the debt greater than the limit induces the firm to run away, then the liquidation of the firm represents the necessary

[8]Ross, Westerfield, & Jordan (1993) and Smith (1977) document that firms raise more than 80% of equity from internal sources. From a theoretical point of view, this can be justified by assuming that there is a sufficiently high proportional cost to funds raised with external sources. The assumption is crucial in order to have a distribution of heterogeneous firms in the amount of equity.

[9]For example, we can assume the following enforceability problem: after receiving the loan, a firm can distribute all the borrowed cash to the shareholders and then declare bankruptcy. In that case, if the liquidation value of the firm's equity is smaller than the debt, the bank will realize a loss with probability one, independently of the interest rate charged in the contract. In order to prevent this moral hazard problem, the bank is willing to make loans to the firm only up to a limit. The incentive-compatibility limit is equal to the value of the firm conditional on the firm implementing a non-deviating (moral hazard) policy. Because the value of a firm is an increasing function of the equity, to simplify the analysis the value of the firm's capital is taken as proxy for the current value of the firm.

outcome of an optimal debt contract: renegotiation of the loan is equivalent to give the firm the opportunity to run away next period, and consequently the loan will never be renegotiable.

The presence of this limit imposes a lower bound to the size of the firm in terms of equity: a firm needs positive value of equity in order to borrow and produce. However, as we will see, in the calibrated economy the borrowing limit is directly binding only for very small firms that, as a group, are quantitatively unimportant in terms of their contribution to aggregate output.

We also assume that at the beginning of each period, and before hiring labor and renting capital, the firm faces a probability η of becoming unproductive (exogenous exit). In that case the firm is liquidated and the liquidation value of capital is given by the function $\ell(e)$, with $0 \leq \ell(e) \leq (1-\delta)e$. The rationale behind this assumption is to allow for the possibility that firms exit the market for reasons other than bankruptcy.

2 The agents' problems

In this section we describe the optimization problems solved by the two main actors of this economy: firms and households.

As is standard in monetary models, we normalize nominal variables (deposits, loans, cash holdings and the nominal price) by the pre-shock stock of money. The states of this economy are then given by the aggregate shock to technology z, the current growth rate of money g, the distribution of firms over equity represented by the probability measure $\mathcal{M}(e)$, the aggregate stock of rental capital K_h, and the nominal stock of households deposits D. Notice that the cash holdings of households can be derived from the stock of normalized deposits and it is equal to $1-D$. Therefore, we do not have to include this variable in the sufficient set of state variables. The set of aggregate state variables is denoted by $s = (z, g, \mathcal{M}, K_h, D)$.

2.1 The Firm's Problem

The managers of surviving firms will seek to rent capital, hire labor and borrow operating cash from financial intermediaries to maximize the value of the firm in terms of utility for the shareholders. The value of the firm for the shareholder derives from the flows of dividends that are paid at the end of each period. Because dividends are paid at the end of the period with cash, the shareholder has to wait until next period to use this cash to buy consumption goods. This implies that one unit of dividend paid at time t allows the shareholder to buy p_t/p_{t+1} units of consumption goods at time $t+1$. Therefore, the expected utility at time t of one unit of dividend also paid at time t is equal to $\beta E_t p_t u_{1,t+1}/p_{t+1}$, where $u_{1,t+1}$ is the marginal utility of consumption at time $t+1$. The term $\beta E_t p_t u_{1,t+1}/p_{t+1}$ will be denoted by $\omega(s)$ and it depends on the states of the economy s. In order to determine the value in terms of utility of the firm's payments to the shareholders, we have to multiply these payments by this factor. Denote by $\Omega(s,e)$ the value in terms of utility for the representative household of a firm with e units of equity. The optimization problem of a surviving firm can then be written as:

$$\Omega(s,e) = \max_{k,l,b} E\left\{ \max_{e'} \left\{ \pi\,\omega(s) + \beta\Omega(s',e') \right\} \,\middle|\, e+\vartheta \geq 0 \right\} (1-\Gamma)(1-\eta) \;+\; \ell(e)\,\omega(s)\,\eta \qquad (8)$$

subject to

$$\pi = e + \vartheta - e' \geq 0 \tag{9}$$

$$pwl + pr_k(k - e) \leq b \leq pe \tag{10}$$

$$\vartheta(s, e, k, l, b, \varphi) = z\,\varphi\,F(k, l) - wl - r_k(k - e) - \delta e - \tilde{r}_l \frac{b}{p} \tag{11}$$

$$\tilde{r}_l(s, e, k, l, b) = \frac{1 + r_l}{1 - \Gamma} - E\left(\frac{p[(1-\delta)e + z\varphi F(k,l)]}{b} \,\middle|\, e + \vartheta < 0\right)\left(\frac{\Gamma}{1 - \Gamma}\right) - 1 \tag{12}$$

$$\Gamma(s, e, k, l, b) = \text{prob}(e + \vartheta \leq 0) \tag{13}$$

The function $\Omega(s, e)$ results from the sum of two terms. The first term is conditional on the event that the firm is productive at the beginning of the period, which happens with probability $1 - \eta$ and does not go bankrupt (where Γ is the probability of failure defined in (13)). The firm defaults when the end-of-period resources, which are given by the equity e plus the net profit ϑ after repaying the loan, are smaller than zero. The second term is the value of a firm which ceases to produce because it is not productive, which happens with probability η. In this case the firm is liquidated and the real liquidation value of its equity is equal to $\ell(e)$.

A productive firm solves two sequential problems at two different stages where each stage is characterized by a different information set. At the beginning of the period, and before observing the shock φ, the firm decides the production scale by choosing k, l, b. At the end of the period, and after observing the shock φ, and therefore, the profits ϑ, the firm decides the next period equity e'. By choosing e', the firm also chooses the dividend to distribute π as specified in equation (9). The dividend cannot be negative which is equivalent to say that the firm cannot raise equity with external sources.

Equation (10) is the cash-in-advance constraint for working capital and the borrowing limit: in order to hire labor and capital, the firm needs to borrow liquid funds from the financial intermediary, and the amount of borrowing cannot exceed the value of the firm's equity. Finally, equations (11) and (12) define, respectively, the firm's profits and the interest rate charged by the financial intermediary. To solve this problem firms need too other objects: the law of motion for aggregate states $H(s)$ and the price function $P(s)$. These functions are taken as given by firms.

In Cooley & Quadrini (1997) we show that the optimal dividend policy of the firm assumes a simple form. Firms will retain profits and build the equity of the firm until it reaches an optimal size $\bar{e}(s)$. The existence of an upper bound in the size of the firm derives from the fact that the value of the firm is increasing and concave. Consequently, the marginal increase in the value of the firm is decreasing in e and there is a point $\bar{e}$ for which the firm is indifferent between increasing the equity and distributing dividends. Notice that this upper limit in the equity size of the firm is not exogenous but it depends on the aggregate states of the economy. The presence of the exogenous probability η of becoming unproductive with a liquidation value of equity $\ell(e) \leq (1 - \delta)e$, guarantees the existence of this upper bound.

In that paper, we also show that earnings are retained in the form of physical capital rather than liquid funds (which would allow the firm to borrow less). The reinvestment of profits in the form of physical capital, rather than liquid funds, derives from the fact that the real interest rate on loans is smaller than the net rental rate of capital $r_k - \delta$. To see why this is the case, let's consider what would be the structure of the interest rates in the steady state equilibrium of this economy when the growth rate of money is positive. Given the particular nature of the monetary policy described before, the interest rate on loans is smaller than the interest rate on deposits. Because in the steady state the real interest rate on deposits is equal to the net rental rate of capital, we also have that the real lending rate is smaller than $r_k - \delta$. Out of the steady state, this interest rate structure may change. However, for the calibrated version of the model, the probability that the real interest rate of loans is bigger than the net rental rate of capital is practically zero.

Simple manipulation of the first order conditions shows that the optimal capital-labor ratio is independent of the scale of production and it is given by:

$$\frac{k}{l} = \frac{\theta}{(1-\theta)} \frac{w}{r_k} \tag{14}$$

Moreover, by imposing sufficient conditions for which the cash-in-advance constraint (10) is binding, the firm's choice reduces to the choice of the scale of production, which in turn depends on the amount of debt b. Using this result, and the optimal dividend policy described above, the firm problem can be reformulated as:

$$\Omega(s,e) = \max_{b} E\left\{ \pi\, \omega(s) + \beta \Omega(s',e') \;\middle|\; e + \vartheta \geq 0 \right\} (1-\Gamma)(1-\eta) \;+\; \ell(e)\, \omega(s)\, \eta \tag{15}$$

subject to

$$\pi = e + \vartheta - e' \tag{16}$$

$$pwl + pr_k(k-e) = b \leq pe \tag{17}$$

$$e' = \begin{cases} e + \vartheta(s,e,b,\varphi), & \text{if} \quad 0 \leq e + \vartheta(s,e,b,\varphi) \leq \bar{e}(s) \\ \bar{e}(s), & \text{if} \quad e + \vartheta(s,e,b,\varphi) > \bar{e}(s) \end{cases} \tag{18}$$

$$\frac{k}{l} = \frac{\theta}{(1-\theta)} \frac{w}{r_k} \tag{19}$$

$$\vartheta(s,e,b,\varphi) = z\varphi F(k,l) - (1+\tilde{r}_l)\frac{b}{p} - \delta e \tag{20}$$

$$\tilde{r}_l(s,e,b) = \frac{1+r_l}{1-\Gamma} - E\left(\frac{p[(1-\delta)e + z\varphi F(k,l)]}{b} \;\middle|\; e + \vartheta < 0 \right) \left(\frac{\Gamma}{1-\Gamma} \right) - 1 \tag{21}$$

$$\Gamma(s, e, b) = \text{prob}(e + \vartheta \leq 0) \tag{22}$$

Equation (18) defines the investment and dividend policies of the firm as described above. As in the previous program, each firm takes as given the law of motion for aggregate states $H(s)$ and the price function $P(s)$.

2.2 The market price of firms' shares

In this section we examine the connection between the market price of a firm—denoted by $q(s, e)$—and the function $\Omega(s, e)$ defined in (8). The function $q(s, e)$ is the real market price of a firm's share that at the end of the period—and therefore, after the payment of dividends—is endowed with e units of equity. The function $\Omega(s, e)$, instead, is the utility value of a firm's share that at the beginning of the period—and therefore before uncertainty is resolved—is endowed with e units of equity. These two functions are related by the following arbitrage condition:

$$q(s, e)E\left\{\frac{\beta p u_1'}{p'}\right\} = \beta E\Omega(s', e) \tag{23}$$

The left hand side of the equation is the cost in terms of utility of paying the price $q(s, e)$ at the end of the period. Notice that the term multiplying the price is the function $\omega(s)$ defined previously. The term on the right hand side, instead, is the expected present value (also in terms of utility) of owning the firm's share in the following period. In equilibrium these two values must be the same. Consequently, the equilibrium market price of the firm is equal to:

$$q(s, e) = \beta E\left\{\frac{\Omega(s', e)}{\omega(s)}\right\} \tag{24}$$

2.3 Entrance of new firms and market price of new firms' shares

In each period new firms will be created with the cash raised thorough the subscriptions of the new firms' shares. There is a fixed cost κ to set up a new firm, and when a new firm is created it becomes productive only with probability $1 - \lambda$. If the firm becomes productive, the firm will run the same production technology of old firms as described above.

The presence of the fixed cost κ is motivated by technical considerations. As we will see, without this cost, the optimal size of a new firm in terms of equity would be zero in the limit and the return from creating new firms will go to infinity. The consequence is that the size of all firms will collapse to the size of new entrants and there would be no firm heterogeneity. The exogenous probability of failure is introduced to control for the optimal size of new entrants. As will be clear below, when λ is zero, the optimal size of new entrants would be close to the maximum size of firms, while in the data new firms are generally small. With a sufficiently large λ, however, the size of new entrant firms will be small. We justify this probability with the empirical observation that small firms face much lower survival probabilities than older firms.

In each period there is an optimal size of new firms that we denote with e_0. This amount of equity maximizes the present return from creating new firms.[10] The market price of a new

[10]This is equivalent to saying that the optimal size of new firms is determined by the size of equity that

firm of size e is denoted by $q^n(s,e)$. This price can be derived following an arbitrage argument similar to the one used in the derivation of the price of old firms[11] in equation (24). The cost of purchasing a new firm in terms of utility is $q^n(s,e)u_1$, while the value of owning it, is $(1-\lambda)\beta E\Omega(s',e)$. Equalizing these two values we get:

$$q^n(s,e) = (1-\lambda)\beta E\left\{\frac{\Omega(s',e)}{u_1}\right\} \tag{25}$$

The real cost to create this new firm is equal to $\kappa + e$. Therefore, the optimal size of a new firm is determined by the following optimization problem:

$$e_0 \;=\; \arg\max_{e>0}\left\{\frac{q^n(s,e)}{\kappa+e}\right\} \;=\; \arg\max_{e>0}\left\{\frac{(1-\lambda)\beta E\Omega(s',e)}{(\kappa+e)u_1}\right\} \tag{26}$$

where the last term has been derived by substituting for the market price of a new firm's share as defined in equation (25).

Figure 1 illustrates graphically how the optimal size of new firms is determined. The figure plots the market price of the new firm $q^n(s,e)$. The concavity of Ω implies that this price is also concave in e. The optimal size of new firms is given by the value of equity for which the line departing from $-\kappa$ is tangent to the curve representing the market price of a new firm. This is because the current return from creating a new firm of size e is given by the slope of the line departing from $-\kappa$ and crossing the new firm value curve at the point e. As can be verified from the picture, the line with the highest slope is the one tangent to the new firm's value curve.

New firms are created until the market price of new firm of size e_0 is equal to its cost, and in equilibrium the following arbitrage condition has to be satisfied:

$$\kappa + e_0 \;=\; q^n(s,e) \;=\; (1-\lambda)\beta E\left\{\frac{\Omega(s',e_0)}{u_1}\right\} \tag{27}$$

Therefore, in equilibrium the optimal size of new firms is given by the point in which the line with slope 1, departing from $-\kappa$, is tangent to the price curve of new firms. Simple comparative static analysis using figure 1 shows that a decrease in λ raises the price curve for new firms and increases the optimal size of new entrant firms. When λ is zero, the optimal size of new firms gets closer to the upper bound $\bar{e}$. The upper bound is at the point in which the slope of $\beta E\Omega(s',e)$ is equal to $\omega(s)$. Both variables e_0 and $\bar{e}$ depend on the aggregate states of the economy and they fluctuate over the business cycle.

2.4 The Household's Problem

The households in this economy choose consumption, labor supply, investment in physical capital, a financial portfolio composed of shares of new and old firms, deposits and cash.

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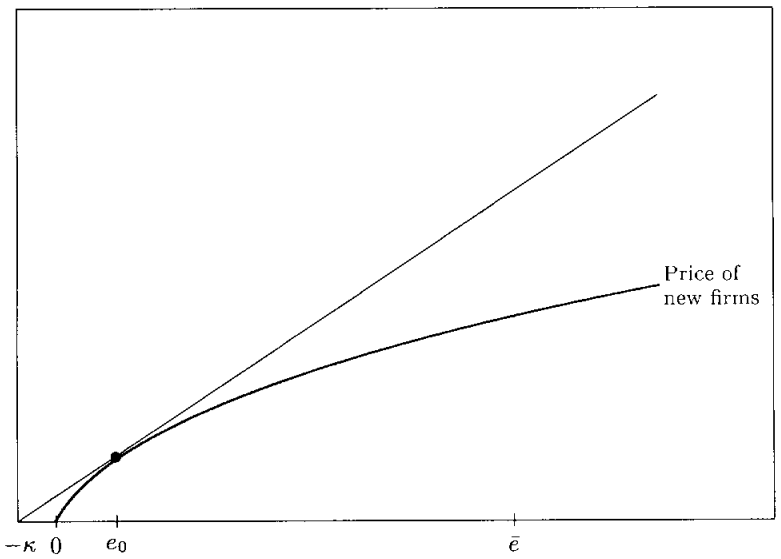
maximizes the value of the portfolio of new firms obtained with the investment of a fixed amount of funds. The problem is not to maximize the surplus of each new firm, but the surplus of the portfolio of all new firms that can be obtained with this fixed amount of resources.

[11] Remember, however, that in the primary market transactions take place at the beginning of the period while in the secondary market transaction take place at the end of the period. One unit of real resources paid at the beginning of the period costs to the agent u_1 units in terms of utility while the cost of one unit of resources paid at the end of the period is ω.

Figure 1: Optimal size of new entrant firms.



Denote by $\hat{s}$ the set of individual states for the households. They are given by the initial portfolio of shares μ, the stock of rental capital k_h, the nominal stock of deposit d and the total stock of nominal assets m (cash and deposits), that is, $\hat{s} = (\mu, k_h, d, m)$. The household's problem, written in recursive form, is:

$$v(s, \hat{s}) = \max_{l,c,i_h,\mu^n,\mu^o,d',m'} \left\{ u(c, 1-l) + \beta E v(s', \hat{s}') \right\} \tag{28}$$

subject to

$$p[c + i_h + q^n(\mu^n)] \leq m - d + pwl + pr_k k_h \tag{29}$$

$$p[c + i_h + q^n(\mu^n)] + pq(\mu^o) + (1+g)m' = m + p\pi(\mu) + r_d d + pwl + pr_k k_h \tag{30}$$

$$k_h' = (1-\delta)k_h + i_h \tag{31}$$

$$\mu' = \psi(s, \mu, \mu^o, \mu^n) \tag{32}$$

Equation (29) is the cash-in-advance constraint for the household, and equation (30) is the

budget constraint. The real market value of the portfolio of net purchases of the existing firms can be written as $q(\mu^o) = \int_e q(s,e)\mu(e)de$, where the market price $q(s,e)$ has been defined before. The function $\pi(\mu) = \int_e \pi(s,e)(\mu(e))de$ denotes the dividends paid on the end-of-period portfolio of old firms μ. The end-of-period stock of money m' is multiplied by the gross growth rate of money $1+g$ as a result of normalizing all nominal variables by the aggregate pre-shock aggregate stock of money M. Equation (31) defines the evolution of the stock of rental capital k_h and (32) the evolution of the household's portfolio of the firms' shares. The households, as the firms, also use the law of motion for aggregate states $H(s)$ and the price function $P(s)$ to solve for this problem.

We impose sufficient conditions for which the cash-in-advance constraint is binding and the first order conditions of the household's problem with respect to l, i_h, d, μ^n and μ^o are:

$$u_{2,t} - wu_{1,t} = 0 \tag{33}$$

$$u_{1,t} - \beta E_t \{(1 + r_{k,t+1} - \delta)u_{1,t+1}\} = 0 \tag{34}$$

$$E_t \left\{ \frac{u_{1,t+1}}{p_{t+1}} - \beta \frac{(1 + r_{d,t+1})u_{1,t+2}}{p_{t+2}} \right\} = 0 \tag{35}$$

$$u_{1,t} - (1-\lambda)\beta E_t \left\{ \frac{[\pi_{t+1}(e) + q_{t+1}(e)]p_{t+1}u_{1,t+2}}{q_t^n(e)p_{t+2}} \right\} = 0 \tag{36}$$

$$\beta E_t \left\{ \frac{p_t u_{1,t+1}}{p_{t+1}} \right\} - \beta E_t \left\{ \frac{[\pi_{t+1}(e) + q_{t+1}(e)]p_{t+1}u_{1,t+2}}{q_t(e)p_{t+2}} \right\} = 0 \tag{37}$$

where $\pi_{t+1}(e)$ is the dividend paid at time $t+1$ by a share of a firm that at the beginning of period $t+1$ is endowed with e units of equity, and $q_{t+1}(e)$ is its after dividend market price (which depends on the next period equity). As explained before, the term $1-\lambda$ in equation (36) is the probability that a new firm survives to the next period (and becomes old). The differences in the right hand sides of equations (36) and (37) derive from the different timing in which stock market transactions in the primary and secondary markets take place.

3 Recursive competitive equilibrium

The definition of equilibria follows.

Definition 3.1 (Recursive equilibrium) *A recursive competitive equilibrium for this economy consists of: (a) Households' decision rules $l(s,\hat{s})$, $\mu^o(s,\hat{s})$, $\mu^n(s,\hat{s})$, $k_h(s,\hat{s})$, $d(s,\hat{s})$, $m(s,\hat{s})$, and households' value function $v(s,\hat{s})$; (b) Firms' decision rule $b(s,e)$ and firms' value function $\Omega(s,e)$; (c) Aggregate demand of loans $B_f(s)$, rental capital $K_f(s)$ and labor $L_f(s)$ from firms; (d) Aggregate supplies of labor $L_h(s)$ and deposits $D_h(s)$, and aggregate demands of next period capital $K_h(s)$, old firms's share $\mathcal{M}^o(s)$ and new firms' shares $\mathcal{M}^n(s)$ from households; (e) Price function $P(s)$ for (w, r_k, r_l, p, q, q^n); (f) Law of motion $H(s)$ for aggregate states $s = (z, g, \mathcal{M}, K_h, D)$. Such that: (a) The decision rules $l(s,\hat{s})$, $\mu^o(s,\hat{s})$, $\mu^n(s,\hat{s})$, $k_h(s,\hat{s})$, $d(s,\hat{s})$, $m(s,\hat{s})$ solve the household's problem (28) and $v(s,\hat{s})$ is the associated household's value function; (b) The decision rule $b(s,e)$ solves the firm's optimization problem (15) and $\Omega(s,e)$ is the associated firm's value function; (c) Prices are competitive and the markets for shares of old*

firms, shares of new firms, loans, capital, labor, and final goods clear; (d) The laws of motion for aggregate states are consistent with individual decision rules of households, firms and financial intermediaries.

4 Calibration

We calibrate the model assuming that a period is a quarter and the discount factor β is equal to 0.985. The household's per-period utility is specified as:

$$u(c, 1-l) = \frac{[c^{\alpha}(1-l)^{1-\alpha}]^{1-\sigma}}{1-\sigma} \tag{38}$$

The utility parameter α is calibrated so that in the steady state the representative household spends 33% of the available time in market activities. The risk aversion parameter σ is set equal to 2.0.

The depreciation rate is set to 0.02 which is consistent with the slightly narrower definition of capital used here. The production technology is characterized by the parameters θ and ν, and by the stochastic properties of the technology shock φ. The parameter ν determines the degree of returns-to-scale. Studies of the manufacturing sector as in Basu & Fernald (1997), find that this parameter is close to 1 and we choose a value of 0.97 . Then, given the value of ν, we choose $\theta = 0.30$. This value of θ generates a capital income share of approximately 35%. We assume the idiosyncratic technology shock to be independently and identically normally distributed with mean $\bar{\varphi}$ and variance σ_{φ}^2.

In the sample of manufacturing firms analyzed by Evans (1987), the average exit rate is about 5% per year. This is the average exit rate we want the model to replicate. However, only a fraction of this exit is due to bankruptcy. We assume that the bankruptcy rate is 1% per year, which is the value reported by Dun and Bradstreet Corporation for the period 1984-92. Consequently, the non-bankruptcy related exit rate is about 4% per year. Based on these assumptions, we set the quarterly exogenous exit rate η equal to 0.01.

The probability of failure for a newly created firm, that is the parameter λ, is important in determining the size of new entrants: larger the value of λ is, smaller the size of new entrants is. By fixing the value of this parameter to 0.25, we keep the size of new entrants relatively small as in the data. Although the exit rate of new firms in the first quarter of life is smaller than 0.25, we should interpret this value as the exit rate of new firms in the first years of life, given that in the model we do not keep track of the age of the firms. The set-up cost κ is determined such that the arbitrage condition for the entrance of new firms in the steady state equilibrium is satisfied.

The liquidation value of equity when the firm becomes unproductive takes the form $\ell(e) = \gamma e$, with $\gamma \leq (1-\delta)$. The parameter γ is jointly determined with the parameters σ_{φ}^2 and γ by imposing the following conditions:

(i) Because the largest firm is representative of very large corporations, we impose that the assets of big firms is about 10,000 times the steady state value of per-capita output. This is an approximation of the asset cut off for small and large firms used in several studies like in Gertler & Gilchrist (1994).

(*ii*) Studies such as Hall & Hall (1993), show that the ratio of long term debt to the firm's assets for large corporations is about 30 percent. We interpret rented capital as long-term debt and we impose that for the largest firms—that are representative of large corporations—the ratio between rented capital and total capital, that is $(k(\bar{e}) - \bar{e})/k(\bar{e})$, is in the steady state 0.30.

(*iii*) The average failure rate is about 0.0025 per quarter. This is the approximate number found by Dun and Bradstreet Corporation for the period 1984-92.

The calibration of the real and monetary shocks is as in Cooley & Hansen (1989). The real shock follows the process:

$$log(z_{t+1}) = \rho_z log(z_t) + \epsilon_{z,t+1} \qquad \epsilon_z \sim N(0, \sigma_z^2) \tag{39}$$

with $\rho_z = 0.95$ and $\sigma_z = 0.00721$. The growth rate of money g follows the process:

$$log(1 + g_{t+1}) = \bar{g}(1 - \rho_g) + \rho_g log(1 + g_t) + \epsilon_{g,t+1} \qquad \epsilon_g \sim N(0, \sigma_g^2) \tag{40}$$

with $\bar{g} = 0.0075$, $\rho_g = 0.49$ and $\sigma_g = 0.0063$. Therefore, we calibrate the quarterly average growth rate of money to 0.75%. The full set of parameter values are reported in table 1.

Table 1: Calibration values for the model parameters.

Intertemporal discount rate	β	0.985
Consumption/leisure share	α	0.380
Relative risk aversion parameter	σ	2.000
Mean idiosyncratic shock	$\bar{\varphi}$	0.034
Standard deviation shock	σ_φ	1.400
Technology parameter	θ	0.300
Return to scale parameter	ν	0.970
Depreciation rate	δ	0.020
Probability of exogenous exit	η	0.010
Absorbing rate for new firms	λ	0.250
Firm initial set-up cost	κ	2.175
Liquidation price of capital	γ	0.700
Growth rate of money	$\bar{g}$	0.007
Autocorrelation money	ρ_g	0.490
Standard deviation money	σ_g	0.006
Autocorrelation real shock	ρ_z	0.950
Standard deviation real shock	σ_z	0.007

5 Steady state properties of the economy

Before exploring the business cycle properties of the artificial economy, it is worth describing some of the steady state equilibrium properties.[12] The firm's production policy resolves the

[12]These features of the model economy are described in more detail in Cooley & Quadrini (1997)

trade-off between the expansion of the production scale, and the greater risk that this expansion implies. As the equity value of the firm grows, the firm can implement larger production plans, even by borrowing more, without increasing its risk. However, because the return to scale decreases as the production scale increases, the firm's debt increases less than the value of equity. Therefore, as the firm grows, the composition of the sources of finance changes in favor of internal sources.

Figure 1a reports the value of debt and the borrowing limit as functions of equity. As can be seen from this figure, the value of debt is increasing in the size of the firm. It is important to note that the borrowing limit is only binding for extremely small firms, and most of the firms choose to borrow less than their possibilities. Figure 1b reports the sources of finance of the firms' total capital: equity, rental capital, and bank debt. If we interpret rental capital as long-term debt, then the three sources of finance are equity, long-term debt and short-run debt which are the conventional categories of firm finance. According to this figure, the use of external sources is a decreasing function of the firm's size. Averaged over all firms, approximately 62% of total capital is financed with equity, 9% with short term debt, and 29% with rented capital.

Figures 1c-1f, plot the expected profits, the expected rate of dividends, the firm's value and the value of Tobin's q (the ratio of market value to book value of assets). Two points are worth noting in these figures. First, the expected dividends rate, that is the amount of dividends as a fraction of equity that the firm expects to pay before the realization of the idiosyncratic shock, is increasing in the firm's size. Second, the value of the firm is strictly increasing and concave, and the degree of concavity decreases with the firm's size. These properties of the firm's dividend policy and the shape of its value function, are important elements that generate an asymmetric response of small and large firms to monetary policy shocks as will be shown below.

Figure 2a plots the probability of failure, which is decreasing in the firms's size, and Figure 2b plots the steady state size distribution of firms. If we exclude the largest class, the steady state distribution is heavily skewed toward small firms which is also an empirical regularity found in the data. The concentration of firms in the largest class occurs because we impose an upper bound on the firm's size. In the data, of course, there exist firms that employ many more workers than the largest firms in the model (3,274 workers). Although the number of these firms is relatively small, they account for a large fraction of aggregate production. We interpret the largest firms in the model as representing the production of very big firms: the large share in production of these big firms is accounted for in the model by an increase in the number of firms rather than their size.

6 The Response of Small and Large Firms.

6.1 Monetary Shocks

Can this model economy, where firms differ simply in the amount of equity and in the idiosyncratic shocks they experience, account for the observed features of U.S. data? Figures 3a-3d report the impulse response of small and large firms after a one standard deviation shock to the growth rate of money. The dividing line between small and large firms is determined so that, in the steady state, small and large firms produce the same output. Using this criterion, the cutting point for equity is approximately 45 percent the value of $\bar{e}$, which is the equity of the

largest firm in the model. The group of small firms includes firms with less than 1,488 employees. The figures show the firms' responses for real debt, rental capital, employment and output, as deviations from the steady state. The reaction to monetary shocks is very different for small and large firms. In particular, small firms respond immediately by increasing the real value of their debt. Big firms, on the other hand, borrow less in real terms. (In nominal terms all firms borrow more, but the increase in the nominal value of debt is greater for smaller firms.) This is consistent with the empirical facts outlined by Gertler & Gilchrist (1994).

To understand the source of this asymmetric behavior we have to consider two effects of monetary policy shocks which are of different importance for small and large firms. On the one hand, a positive monetary shock causes a fall in the interest rate on loans. This lowers the marginal cost of financing production plans which creates an incentive to expand production. At the same time, however, the monetary shock increases the next period inflation rate and this reduces the value of the dividends paid in the current period for the household. This is because dividends are paid with cash at the end of the period and the household has to wait next period to use this cash to buy consumption goods. Remember that one unit of real dividend distributed today provides utility $\omega(s) = E(\beta p u_1'/p')$ to the household. This factor decreases after a positive monetary shock. In the firm's optimization problem, this means that relatively more weight is given to future dividends (the future value of the firm) and relatively less weight to current dividends. This second effect reduces the desire to borrow more that is due to the reduction in the interest rate, because more borrowing carries with it a higher volatility of profits and a higher risk of failure. This effect differs in importance for small and large firms.

To illustrate this, consider the following simplified version of the firm's optimization problem:

$$\max_b E\{\pi(b)\,\omega + \beta\Omega(e'(b))\} \tag{41}$$

where $\pi(b)$ is the dividend paid this period, $\Omega(e'(b))$ is the next period value of the firm, and the function ω has been defined before.

The firm is optimizing over the sum of two factors, $E\{\pi(b)\,\omega\}$ and $E\{\beta\Omega(e'(b))\}$. An expected increase in profits allows the firm to increase either the payment of dividends this period, or the equity of the firm next period, that is the next period value of the firm. While current dividends enter the objective function of the firm linearly, the next period value of equity enters thorough the function Ω, which is a concave function (see Figure 1e). This implies that, if the firm attributes full weight to current dividends, that is, if the firm will distribute all the realized profits, then the firm's problem reduces to the maximization of expected profits and the volatility of the possible realizations of profits is not relevant. On the other hand, if the firm does not distribute dividends in the current period and puts full weight on the maximization of the expectation of the next period value of the firm, then the straight maximization of the expected profits is not optimal. The concavity of Ω implies that an increase in the volatility of profits reduces the next period expected value of the firm. Consequently, the firm does not expand the production scale until the point in which the expected profits are maximized, because this also implies a higher volatility of profits, and therefore, of next period equity. Therefore, the optimal production scale can be seen as the result of solving this trade-off: on one hand there is an incentive to expand production because it allows higher expected profits, on the other there is an incentive to reduce production in order to reduce the volatility of profits. The greater is

the expected dividend compared to the discounted next period expected value of the firm, the larger is the optimal production scale.

A positive monetary shock changes the value of the first factor (value of current dividends) in the firm's optimization problem more than the second factor (next period value of the firm). Consequently, those firms that distribute dividends (or have a significant positive probability of distributing dividends) start giving more importance to the future value of the firm and become more averse to uncertain profits. This impact is particularly severe for large firms to the point in which, after a positive monetary policy shock, they reduce the production scale rather than expanding it, as shown in Figure 3d. The higher weight attributed to future dividends, relative to current dividends, however, is only relevant for large firms. The crucial difference between small and large firms is that small firms do not expect to pay dividends, while big firm do (see Figure 1d). In the objective function of small firms the term $E\{\pi(b)\,\omega\}$ is negligible. As a result, the expansionary impulse induced by the reduction in the interest rate on loans is not compensated by this second effect and a small firm takes on more debt and expands production.

6.2 Productivity Shocks

In contrast to the responses to a monetary shock, small and large firms do not respond differently to productivity shocks. As is shown in Figure 4a-4d, all firms increase their real debt and output in response to a positive productivity shock. It is important to point out that the output responses of the two groups of firms shown by Figure 4d, do not look very persistent. This is because the responses are plotted for a constant number and composition of firms. As we will see, the response of aggregate output is much more persistent due to the change in the distribution of firms. After a positive shock to technology, existing firms become bigger and, as shown by figure 6h, the number of new entrants increases. Firm heterogeneity thus provides a source of propagation that is not present in the standard real business cycle model.

7 The Response of the Aggregate Economy.

Figures 5a-5h show the aggregate response of several variables to monetary shocks while Figure 6a-6h show the same responses to productivity shocks. After a monetary shock, output, wages and prices go up while the nominal interest rate goes down. This is standard in limited participation models as in Christiano & Eichenbaum (1995). The model also generates a response of firms' profits which is consistent with the data.

It is worth emphasizing that the model economy developed in this paper shows a persistent response of output to monetary shocks. Other monetary models have found it difficult to capture any degree of persistence as shown by Fuerst (1995). Following a monetary shock, output (as well as hours and wages) increases for two periods and then returns to the steady state level. The main mechanisms that generates this persistent responses comes from the persistent fall in the interest rate on loans and the increase in the total capital accumulated in the economy. In the case of technology shocks, output also displays high persistence[13] This persistence is mainly

[13]Although the response is not hamp-shaped, the persistence is much higher than the persistence generated by the standard neoclassical business cycle model.

driven by the entrance of new firms, and therefore, by an increase in the number (measure) of firms.

Figures 5g-5h and 6g-6h show the industry dynamics response to monetary and productivity shocks. After a positive shock to the growth rate of money, the failure rate increases while the entrance of new firms decreases in the first response period. The failure rate increases because small firms expand production and take on more debt to take advantage of the reduction in the lending rate. The entrance rate decreases at first because the increase in future prices increase the opportunity cost of buying a new firm in terms of current consumption. (Remember that investment in new firms has to be made with cash). After a technology shock, the failure rate is only increasing in the first period (the high productivity induces firms to take on more risk) but then falls persistently below the steady state value. This is because with the entrance of new firms, the demand of loans increases and this induce an increase in the interest rate on loans. As a result of that each firm takes less debt and faces lower probability of failure. The entrance of new firms is now stimulated by the increase in the market price of new firms. In general we observe that the response of the economy to technology shocks is much stronger and generally more persistent.

We summarize the business cycle properties of this economy in Table 2 which reports the standard deviations of several aggregate variables. This model generates business cycle properties for consumption, hours, investment, and so on that are very similar to those produced by standard real business cycle models. In particular, the model under-predicts the volatility of hours and consumption. It is interesting to note that the model generates a positive correlation between output and capital income share which is a typical feature of the data.

The second and third columns of Table 2 show the behavior of the economy when it is driven only by monetary shocks (second column) and only by real shocks (third column). The comparison of the statistics reported in the three columns show that monetary shocks play a marginal role in generating output fluctuations, a result that is consistent with the empirical findings of Leeper et al. (1996). However, as we will see in the next section, we will reach a different conclusion regarding the importance of these shocks for stock market fluctuations.

8 The Response of Financial Markets

In this section we analyze the response to shocks and the business cycle properties of stock market prices and returns. We consider two measures of stock market prices, and their corresponding returns. The first price measure is given by the value of a constant portfolio of firms. The portfolio composition and dimension is kept constant and it is given by the steady state distribution of firms. The value of this portfolio is the sum of the market prices of the firms' shares traded at the beginning of the period with cash, weighted by the portfolio composition. This measure of the stock market value is the closest to standard stock market indices like the S&P 500 index. Formally, we compute it as:

$$I_t^1 = \int_0^{\bar{e}} q_t(e)\, \mathcal{M}^*(e)\, de \tag{42}$$

where $q_t(e)$ is the market price of a firm with e units of equity at the beginning of the period when stock market transactions take place. As shown in (24), this price is given by $q_t(e) =$

Table 2: Business cycle properties of the artificial economy.

	Standard deviation			
	Both shocks	Money shock	Real shock	U.S. Economy
Output	1.20	0.13	1.21	1.67
Consumption	0.49	0.12	0.48	0.84
Investment	4.37	0.59	4.38	8.24
Hours	0.48	0.15	0.46	1.50
Capital	0.34	0.13	0.32	0.62
Wage	0.65	0.13	0.64	0.86
Profits	3.06	0.36	3.08	9.15
Capital share	1.42	0.16	1.42	0.70
Price index	1.28	0.72	1.07	1.39
Inflation	1.12	0.71	0.87	0.57
	Correlation with output			
	Both shocks	Money shock	Real shock	U.S. Economy
Consumption	0.94	0.52	0.96	0.84
Investment	0.98	0.70	0.99	0.91
Hours	0.96	0.99	0.99	0.83
Capital	-0.32	0.90	-0.39	-0.08
Wage	0.98	0.99	0.99	0.27
Profits	0.99	0.72	0.99	0.74
Capital share	0.97	-0.98	0.99	0.15
Price index	-0.79	0.39	-0.99	-0.51
Inflation	-0.28	0.31	-0.39	0.34

NOTES: Statistics for the model economy are computed on HP detrended data generated by simulating the model for 200 periods and repeating the simulation 200 times. The statistics are averages over these 200 simulations. Statistics for the U.S. economy are computed using HP detrended data from 1959.1 through 1996.4. Consumption includes consumer expenditures in non-durable and services. Consumer durables are classified as investment. Wages is the index of real compensation per hour in the non-farm business sector. Profits are corporate profits and the price index is the CPI index.

$\beta E_t \Omega_{t+1}(e)/\omega_t$, where $\omega_t = E\beta p_t u_{1,t+1}/p_{t+1}$ and $\Omega_t(e)$, defined in (8), is the value of the firm in terms of utility. $\mathcal{M}^*(e)$ is the steady state measure of firms. We will refer to I^1 as the stock market index.

In order to compute the stock market return, we also need to compute the market value of this portfolio at the beginning of next period. This price, denoted as $\hat{I}^1_{t+1}$, is different than I^1_{t+1} because some of the firms included in the original portfolio do not survive to the next period. Define $\hat{\mathcal{M}}^*$ to be the end-of-period measure of surviving firms from the steady state distribution. This value is given by:

$$\hat{I}^1_{t+1} = \int_0^{\bar{e}} q_{t+1}(e)\, \hat{\mathcal{M}}^*(e)\, de \tag{43}$$

The ex-post stock market return index is then given by:

$$r^1_{t+1} = \frac{\hat{I}^1_{t+1} + \pi^1_{t+1} - I^1_t}{I^1_t} \tag{44}$$

where π^1_{t+1} is the cash payment (dividends) received by a shareholder that owns the portfolio $\mathcal{M}^*$.

The second measure of stock market index, denoted by I^2_t, is given by the value of the (non-constant) portfolio representative of all firms in the economy. The difference between this stock market index and the previous one is that the composition and dimension of the portfolio changes as the distribution and number of firms in the economy change. Formally, it is computed as:

$$I^2_t = \int_0^{\bar{e}} q_t(e)\, \mathcal{M}_t(e)\, de \tag{45}$$

where now $\mathcal{M}_t$ is the effective measure of firms at the beginning of period t. This distribution of firms is not constant and it changes over the business cycle. As can be noticed, the difference between (42) and (45), is in the use of a constant weight in the first case, and a variable weight in the second. The ex-post market return is equivalently defined as in equation (44), where $\hat{I}^1$, π^1, and I^1 are replaced by $\hat{I}^2$, π^2, and q^2.

Figures 7 and 8 report the impulse response of stock market prices and returns after one standard deviation shock to the growth rate of money and to aggregate technology, for the two measures of stock market prices and returns. The graphs use the same scale in plotting the impulse responses of the same variable after a monetary and real shocks, and therefore, the responses for the same variable are comparable in magnitude.

From these graphs we notice that both monetary and real shocks produce fluctuations in stock market returns of similar magnitude. This is in contrast to the response of real variables we have seen in Figures 5a-5h and in Figures 6a-6h, in which real shocks are far more important than monetary shocks. Plots 7 and 8 also report the responses of dividends which help us understand the forces that drive the price and return responses.

Table 3 reports standard deviations for each of the two measures of stock market prices and returns for three versions of the economy: the economy with both monetary and real shocks, the economy with only monetary shocks, and the economy with only real shocks. The table also reports the standard deviations of the dividend yields associated with the two concepts of stock market price. The comparisons of these three versions of the model allow us to evaluate

Table 3: Business cycle properties of stock market prices, returns and dividend yield.

	Standard deviation		
	Both shocks	Money shock	Real shock
Stock market prices			
- Stock market index I^1	0.26	0.20	0.15
- Stock market index I^2	0.64	0.08	0.65
Stock market returns			
- Stock market index I^1	18.48	12.73	13.38
- Stock Market Index I^2	18.49	12.73	13.39
Dividend yields			
- Stock market index I^1	1.20	0.54	1.08
- Stock market index I^2	1.60	0.73	1.43

NOTES: Standard deviation of real stock market return 8.2%. Standard deviation of real dividend yield 0.7%. Monthly observations from 1957.1 through 1994.4 compounded to quarterly frequencies.

the importance of monetary and real shocks for stock market fluctuations. As was expected from the analysis of the impulse responses, monetary shocks generate significant stock market fluctuations even though they are quantitatively unimportant in generating fluctuations in real variables. It is also interesting to observe that, as in the data, the model generates much more volatility in the stock market returns than in the dividend yields.

Finally Table 4 reports the correlations of stock market values, returns and dividend yields with several variables. Of particular interest is the positive correlation between the growth rate of money and the stock market return, and the negative correlation between the inflation rate and the stock market return, that are both features of the data. It is important to point out that only with the inclusion of technology shocks the model is able to generate this negative correlation. With only monetary shocks the correlation would be positive. The negative correlation between inflation and the stock market returns has also been analyzed by Jovanovic & Ueda (1998).

9 Conclusion

The financial decisions of firms differ systematically across firms of different sizes. This, coupled with idiosyncratic shocks to the productive abilities of firms explains many of the features of firm entry and exit. Small firms trade off their desire to grow faster by borrowing to finance more ambitious production plans against the increased volatility that the borrowing entails. When firms become large the desire to grow becomes less important than the desire to minimize the probability of failing. More importantly, these features of firm decision making explain the different responses of large and small firms to changes in monetary policy.

Firm heterogeneity and the differences in financial decisions of large and small firms is an important propagation mechanism for both technology and monetary shocks. It leads to a persistent impact of monetary policy shocks on output. Quantitatively, however, the impact of money on output is very small. Nevertheless, we show that monetary policy shocks lead to considerable volatility in financial markets, particularly in stock market returns.

Table 4: Correlation of stock market prices, returns and dividend yield with output, money growth, price level, inflation.

	Correlation			
	Output	M. growth	Nom. price	Inflation
Stock market prices				
- Stock market index I^1	0.48	0.73	0.03	0.05
- Stock market index I^2	0.95	-0.07	-0.83	-0.31
Stock market returns				
- Stock market index I^1	0.28	0.49	0.05	-0.20
- Stock market index I^2	0.28	0.49	0.05	-0.20
Dividend yields				
- Stock market index I^1	0.82	-0.45	-0.95	-0.55
- Stock market index I^2	0.82	-0.39	-0.91	-0.33

NOTES: In the data correlation output-stock market return -0.26; correlation money growth-stock market return 0.16; correlation inflation-stock market return -0.28.

A Appendix: Computational procedure

We describe first the computational procedure to solve for the steady state equilibrium and then the algorithm used to compute the equilibrium with aggregate uncertainty.

A.1 Solving for a steady state equilibrium

Before starting the computational procedure to solve for a steady state equilibrium, we have to fix the values of all parameters. Some of these parameters, however, cannot be determined by deriving simple equilibrium equations and requires an iterative procedure. We start by guessing the values of four parameters: α, γ, $\bar{\varphi}$ and σ_φ. We also have to fix the value of some variable as a normalization unit. We choose to set $\bar{e} = 100$ which acts as a scaling factor for the model.

At this point we start the computational procedure by guessing the steady state values of three variables: the wage rate w, the labor supply L and the stock of nominal deposits D. With these guesses, the following equations determine the steady state values for consumption C, the real rental price for capital r_k, the nominal interest rate on deposits r_d, and the nominal interest rate on loans r_l.

$$\frac{1-\alpha}{\alpha}\frac{C}{1-L} = w \tag{46}$$

$$r_k = \frac{1}{\beta}[1-\beta(1-\delta)] \tag{47}$$

$$r_d = \frac{1}{\beta}(1+g) - 1 \tag{48}$$

$$r_l = \frac{r_d D - g}{D+g} \tag{49}$$

Equations (46), (48), (47) and (49) are derived from equations (33), (34), (35) and (5), after imposing steady state conditions.

Given the prices w, r_k, r_l, p and the upper bound $\bar{e}$, the steady state optimization problem of the firm is well defined. Solving for the firms' problem and aggregating allows us to derive the demand for

labor, rental capital and loans and to check for the market clearing conditions and for the optimality of $\bar{e}$. If these conditions are not satisfied, we update the guesses for w, L and D until all market clearing conditions are satisfied. Following is the detailed description of the sequential steps to compute the steady state equilibrium.

1. Guess initial values for w, L, D.
2. Using conditions (46), (47), (48), (49), compute the steady state values of consumption C, and prices r_k, r_d, r_l.
3. Choose a discrete grid in the space of firms' equity, *i.e.*, $e \in \mathcal{E} \equiv \{e_1, ..., e_n\}$. In this grid, $e_1 = 0$ and $e_n = \bar{e}$.
4. Guess initial steady state values of debt b_i^*, $i \in \{1, .., n\}$.
5. Guess initial values for Ω_i, $i \in \{1, .., n\}$.
6. Approximate with a second order Taylor expansion the function $\tilde{\Omega}_i$ around the guessed points for the steady state values b_i^*. This function is defined as:

$$\begin{aligned} \tilde{\Omega}_i(b) &= \beta \sum_{j=1}^{n-1} \int_{e_j}^{e_{j+1}} \left[\Omega_j + \left(\frac{\Omega_{j+1} - \Omega_j}{e_{j+1} - e_j} \right) (x - e_j) \right] \Phi_i(b)(dx) \\ &+ \int_{e_n}^{\infty} [(x - e_n)\omega + \beta \Omega_n] \Phi_i(b)(dx) \end{aligned} \tag{50}$$

   where $\Phi_i(b)$ is the density function for the end-of-period firm's resources, that is, $x = e_i + \vartheta_i(b)$. The function $\tilde{\Omega}_i$ is the approximated utility value of the firm with equity e_i and debt b, conditional on being productive (which happens with probability $1 - \eta$). The function ω is constant in the steady state and it is equal to $\beta u_1/(1 + g)$. The value function Ω is approximated with piece-wise linear functions joining the grid points on which the value function is computed. The definition of $\tilde{\Omega}_i$ given in (50), takes as given the dividend policy of the firm consisting in retaining all profits until the firm reaches the size e_n.
7. Solve for the firm's policy b_i by differentiating the function $\tilde{\Omega}_i(b)$ with respect to b.
8. Eliminate b from $\tilde{\Omega}_i$ using the policy rules found in the previous step and take these values to guess new values for Ω_i. Then restart the procedure from step 6 until all firms' value functions have converged.
9. After value function convergence, check whether the firm policies found in step 7 reproduce the guesses for the steady state values of debt b_i^*. If not, update this guesses and restart the procedure from step 5 until convergence.
10. Find the optimal size of new firms e_0 and the set-up cost κ using the conditions:[14]

$$\beta(1 - \lambda)\Omega(e_0) = (\kappa + e_0)u_1 \tag{51}$$

$$(1 - \lambda)\beta \frac{\partial \Omega(e)}{\partial e}\bigg|_{e = e_0} = u_1 \tag{52}$$

[14] If we were able to determine the function $\Omega(e)$ exactly, then the point e_0 would be the tangent point to the 45 degree line departing from $-\kappa$, and given the concavity of Ω, this point would be unique. Because in the computational procedure the function Ω is approximated with peace-wise linear functions, then, although unlikely, it is possible that a full linear segment of the function coincides with the 45 degree line. In that case we assume that there is an equal probability for new firms to be of the two sizes.

11. Given the size of new entrants, iterate on the measure of firms until convergence. In each iteration, it is assumed that the measure of new entrants is equal to the measure of exiting firms. In that way the total measure of firms is kept constant.

12. Using the steady state distribution of firms, compute the demand for labor, rental capital and the dividends distributed π. In addition, compute the investment in the creation of new firms $I_n = \mathcal{M}^n(\kappa + e_0)$, where $\mathcal{M}^n$ is the measure of new entrant firms (of size e_0).

13. The measure of firms is rescaled such that the demand for labor is equal to the guess L. Then, using the market clearing condition for loans $p(r_k K_h + wL) = D + g$, determine the price index p.

14. At this point there are three conditions that need to be verified: 1) the households' cash-in-advance constraint $p(\delta K_h + I_n + C) = 1 - D + pwL + pr_k K_h$; 2) the households' budget constraint $(1 + g) = (1 + rd)D + p\pi$; 3) the optimality of the upper bound e_n. The optimality of e_n requires that the following condition is satisfied:

$$\beta \frac{\partial \Omega(e)}{\partial e}\bigg|_{e = e_n} = \omega \tag{53}$$

    In order to check for this condition, we compute the numerical derivative of $\Omega(e)$ at e_n, taking as given the value of b_n^* found before. If the three conditions are not satisfied, update the initial guesses for w, L, D, and restart the procedure from step 2 until convergence.

At this point a steady state equilibrium has been computed. We have to check, however, whether all calibration targets are satisfied. Specifically, we have to check that: $L = 0.33$, $e_n/Y = 10{,}000$, $(k(e_n) - e_n)/k(e_n) = 0.25$, and the average probability of failure is 0.0025. If not, the guesses for the parameters α, γ, $\bar{\varphi}$ and σ_φ are updated and the whole procedure restarted.

A.2 Solving for the equilibrium with aggregate uncertainty

Solving for the steady state equilibrium is the first step toward the solution of the model economy with aggregate uncertainty. Given the steady state equilibrium variables, we seek for Markovian decision rules of the firms and of the representative household.

At each point in time the states of the economy are: (a) the aggregate technology shock z; (b) the monetary shock (growth rate of money) g; (c) the distribution of firms over real equities represented by the probability measure $\mathcal{M}$; (d) the stock of rental capital K_h; (e) the nominal stock of deposits D (which has been normalized by the pre-shock nominal stock of money). The set of states are denoted by $s = (z, g, \mathcal{M}, K_h, D)$. Note that the households' cash holdings is also a state variable; however, given our normalization, this variable can be derived from the stock of normalized deposits D, and it is equal to $1 - D$.

Given the computational difficulties associated with the derivation of function of measures, the distribution of firms $\mathcal{M}$ has to be approximated with some of its moments. We approximate the distribution with two variables: the aggregate value of equity owned by new firms (new entrants), that we denote by E_0, and the aggregate value of equity owned by old firms (firms with more than one period of age), that we denote by E. Therefore, as in Krusell & Smith (1998), we approximate the distribution of agents (in our case young and old firms) with the first moments E_0 and E_1. However, the procedure followed to derive the laws of motion of these moments is different than the one used in Krusell and Smith and, as explained below, it consists in the aggregation of individual decision rules. Following is the description of the sequential steps of the whole procedure.

1. Discretize the space of firms' equity as in the computation of the steady state equilibrium described in the previous section.

2. Guess a linear functions $H(s)$ for the law of motion of the aggregate states and a linear function $P(s)$ for prices. The function H maps the current states $s = (z, g, E_0, E_1, K_h, D)$ into next period states and P maps the current states into the current prices $h = (w, r_k, r_l, p)$. In addition, we also guess a liner function for the term $\omega(s) = E[\beta u_1'/(p'(1+g))]$. Given this function and the functions H and Q, the firm's problem is well-defined.

3. Guess initial quadratic (firms' value) functions $\Omega_i(s)$, $i = \{1, ..., n\}$.

4. Given the guesses for $\Omega_i(s)$, approximate with a second order Taylor expansion the function $\tilde{\Omega}_i$ defined as:

$$\tilde{\Omega}_i(s, h, b, \omega, s') = \tag{54}$$

$$\beta \sum_{j=1}^{n-1} \int_{e_j}^{e_{j+1}} \left[\Omega_j(s') + \left(\frac{\Omega_{j+1}(s') - \Omega_j(s')}{e_{j+1} - e_j}\right)(x - e_j)\right] \Phi_i(s, b)(dx)$$
$$+ \int_{e_n}^{\infty} \left[p[x - e_n]\omega + \beta\Omega_n(s)\right] \Phi_i(s, b)(dx)$$

for $i \in \{1, .., n\}$, where b is the nominal firm's debt (normalized by the pre-shock stock of money). As in the computation of the steady state, $\Phi_i(s, b)$ is the density function for the end-of-period resources $x = e_i + \vartheta_i(s, b)$, which now also depends on the aggregate states. A simplifying assumption, here, consists in taking the size of the largest firm to be fixed at the steady state value e_n.

5. Using the law of motion H eliminate the next period states s' and using the function $\omega(s)$ eliminate ω.

6. Taking derivatives with respect to b of the functions $\tilde{\Omega}_i$, derive the firm's decision rules $b_i(s, h)$, $i = \{1, .., n\}$ which are linear functions of s and h. If the firm is financially constrained, then the policy rule is simply given by a linear approximation of the borrowing constraint.

7. Using the decision rules $b_i(s, h)$, eliminate the variable b from the firms' objective function and, using the function P, eliminate the prices h. After reducing, the functions $\tilde{\Omega}_i$ depend only on the states s. These are used to form the new guesses for the firms' value functions. The procedure is then restarted from step 4 until all value functions have converged.

8. Using the decision rules found in step 6, derive the aggregate demand for loans by summing the individual decision rules of new and old firms weighted by the steady state distribution. In that way we get a linear demand for loans from new firms $B_0^d(s, h)$ and a linear demand for loans from old firms $B_1^d(s, h)$. These two demands are then multiplied by the factors E_0/E_0^* and E_1/E_1^* respectively, and they are linearized around the steady state. By summing these two linear functions we get the aggregate demand for loans $B^d(s, h)$. The computational approximation, here, consists in assuming that when the mean values of equity for new and old firms increase, then the mass of all new and old firms increases proportionally. Using the demand for loans and the firms' demands for labor and rental capital, as well as the function linking the supply of loans to the supply of deposits, approximate with linear functions the demands for labor $L^d(s, h)$, for rental capital $K_d^d(s, h)$ and deposits $D^d(s, h)$. Furthermore, given the optimal decision rules of the firms, linearize the function for the next period value of equity of existing firms $E_1(s, h)$, and the function of dividends distributed by existing firms $\pi(s, h)$. The derivation of these functions is similar to the derivation of the demands.

9. Using the derived demands for labor, rental capital, loans and the linearized household's budget constraint, impose market clearing conditions (demands equal supplies) and compute the prices $h = (w, r_k, r_l, p)$ as a function of the states s, the labor supply L and the household dividends π. Denote this function by $h = \tilde{P}(s, L, \pi)$.

10. Given the price function $\tilde{P}(s, L, \pi)$, the dividend function $\pi(s, h)$ and the next period equity of all firms $E_1(s, h)$, the household's decision rules for the variables L, E_0', K_h', D' are derived using the household's first order conditions, that is equations (33), (34), (35) and (36). The decision rules are computed with the method of undetermined coefficient after linearizing the households first order conditions around the steady state. In equation (36) it is assumed that the size of new entrants is fixed at the steady state value.

11. The solution of the household problem allows the derivation of L, E_0', K_h', D' as linear functions of the states s. These functions, together with the functions $\tilde{P}(s, L, \pi)$, $\pi(s, h)$ and $E_1(s, h)$, allows us to derive the law of motion $H(s)$ and the price function $P(s)$. Also, using these rules, approximate the function $\omega(s)$ with a new linear function.

12. The law of motion for the states, the price function and the function for ω found in the previous step are the new guesses for $H(s)$, $P(s)$ and $\omega(s)$. The procedure is then restarted from step 3 using these new guesses until full convergence.

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Figure 1a – Short-term debt

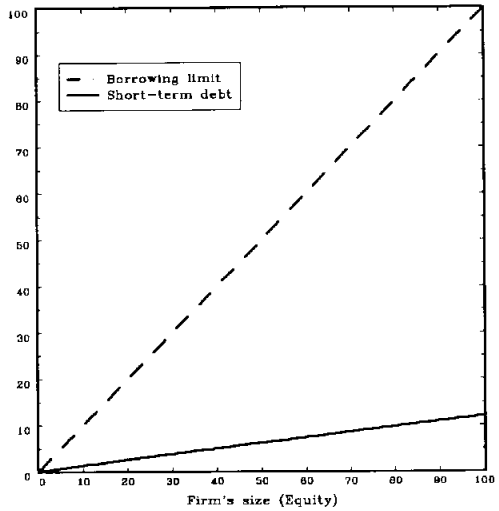

Figure 1b – Sources of finance

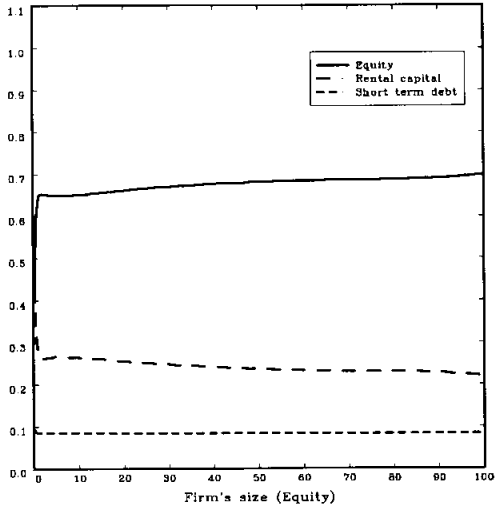

Figure 1c – Expected profit rate

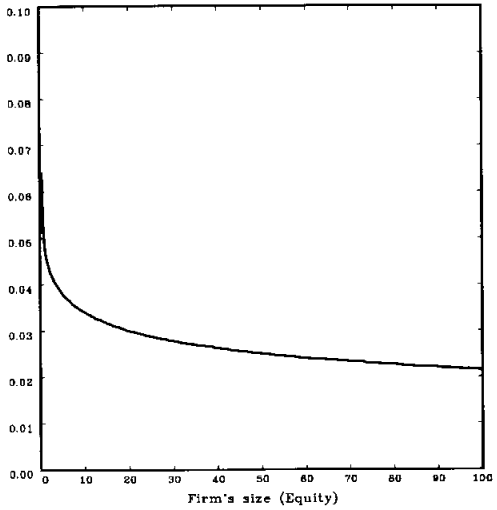

Figure 1d – Expected rate of dividend

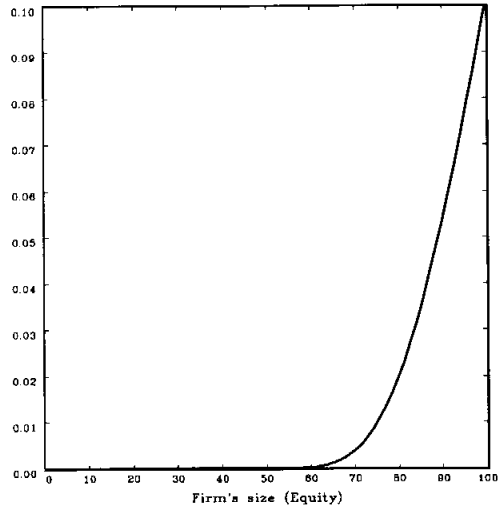

Figure 1e – Firm's value

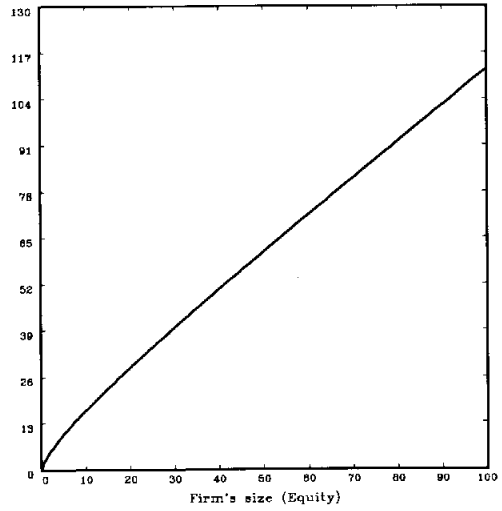

Figure 1f – Tobin's q

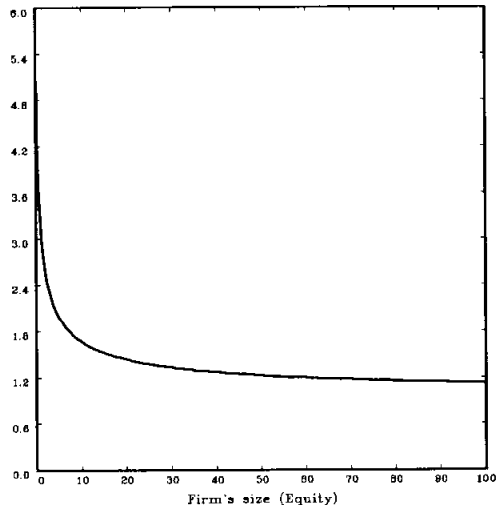

Figure 2a – Failure rate

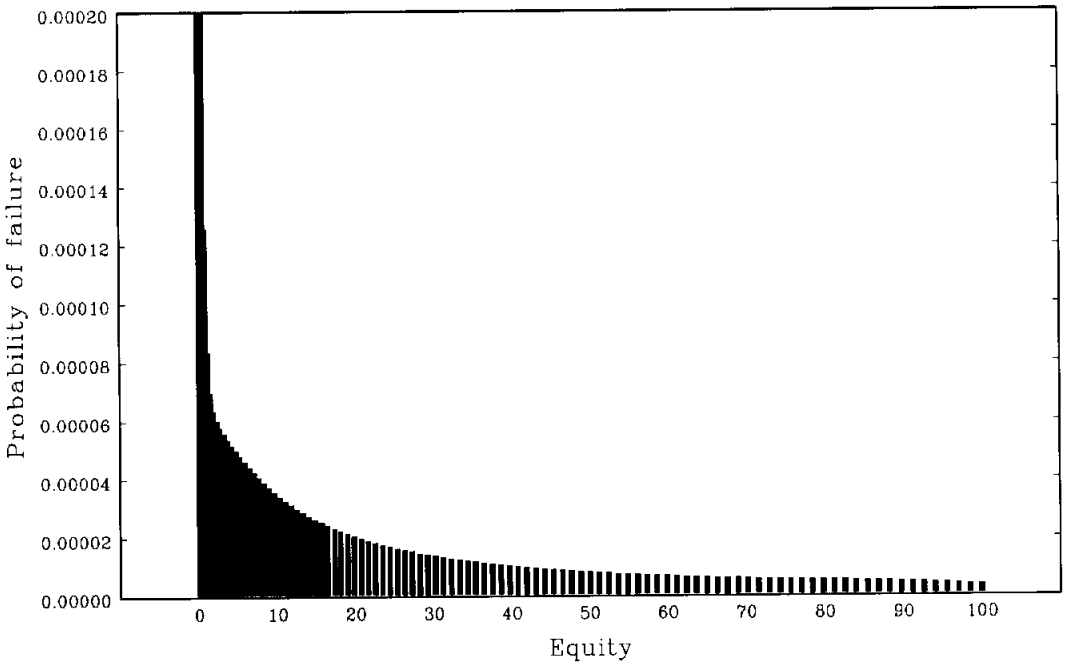

Figure 2b – Stationary distribution of firms

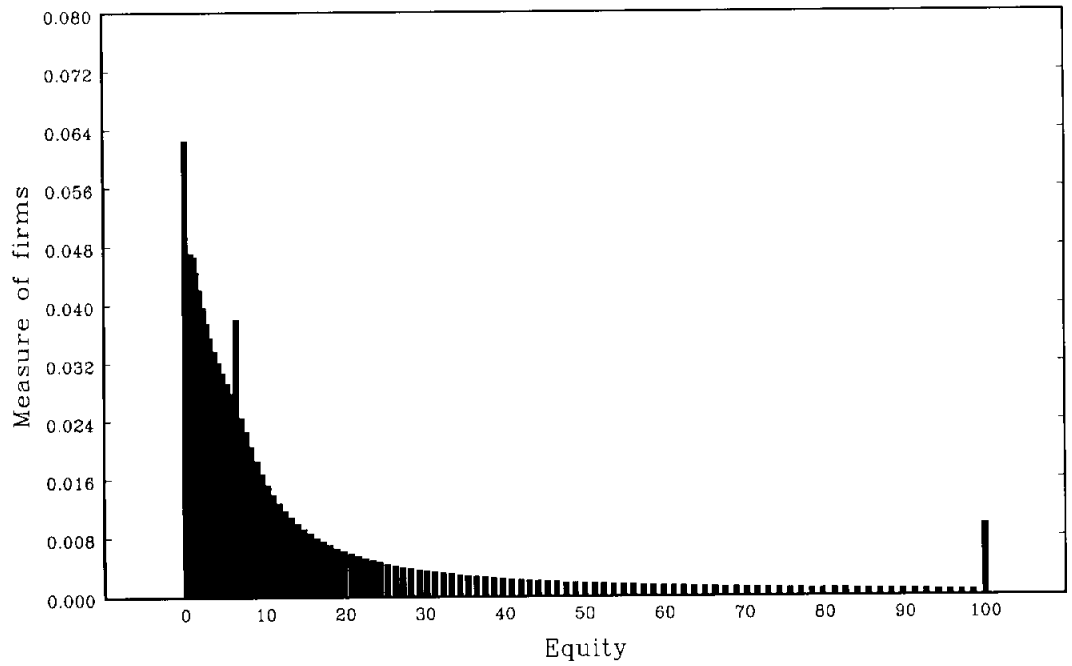

Figure 3a – Real debt

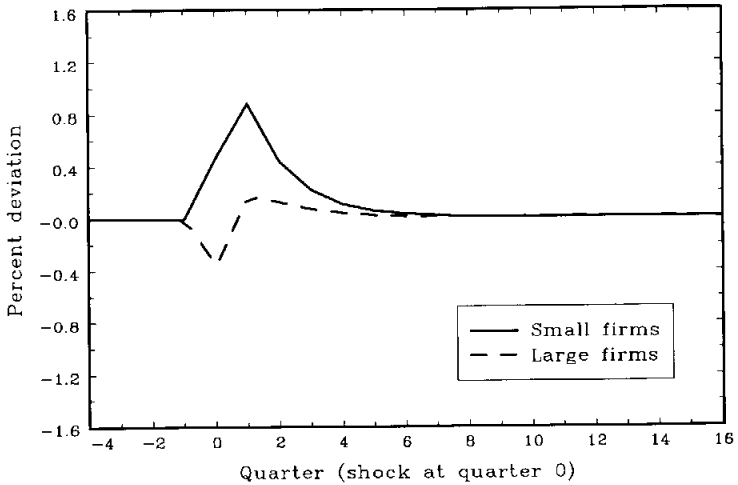

Figure 3b – Rental capital

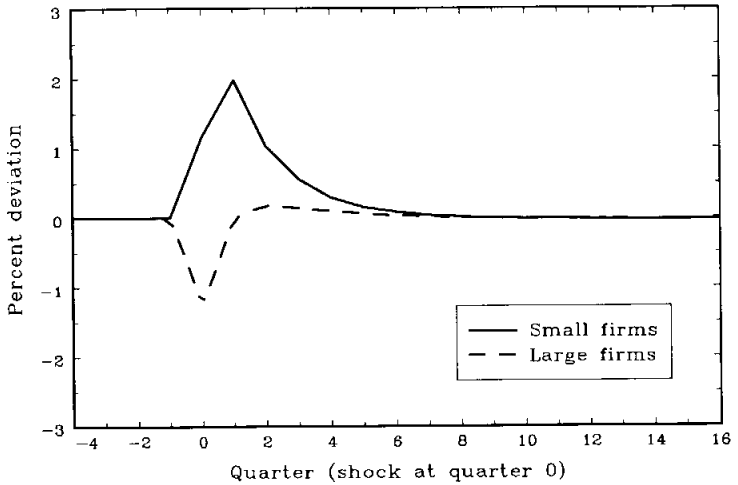

Figure 3c – Employment

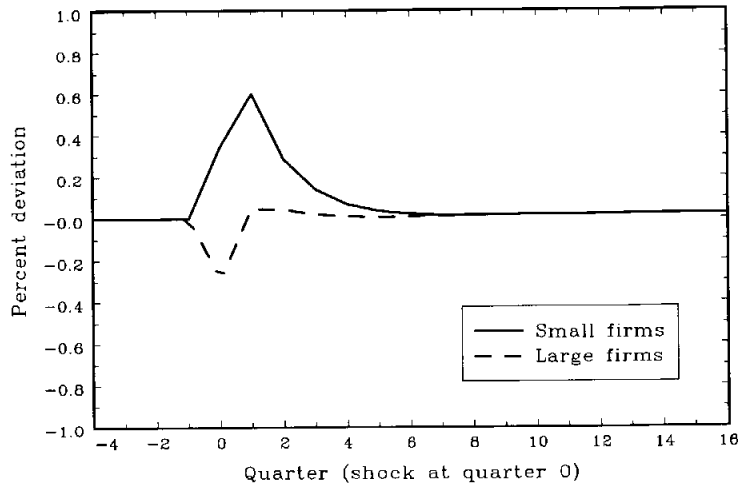

Figure 3d – Production

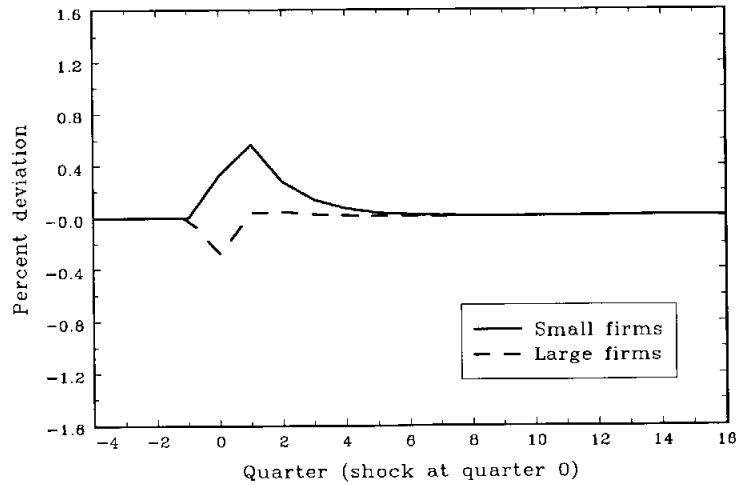

Figure 4a – Real debt

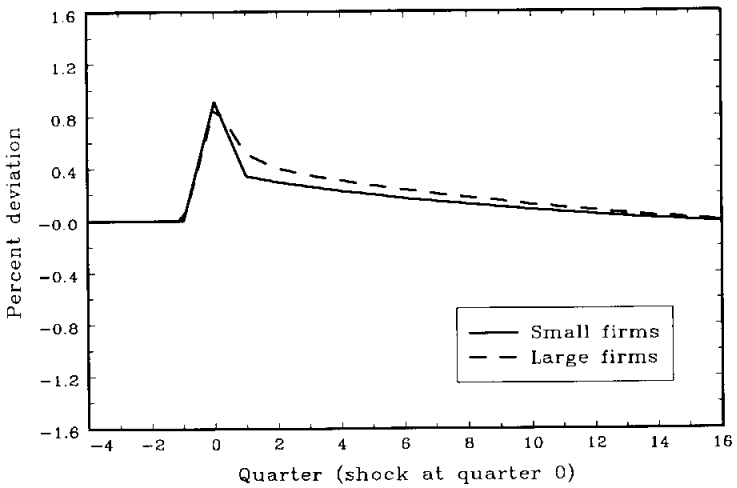

Figure 4b – Rental capital

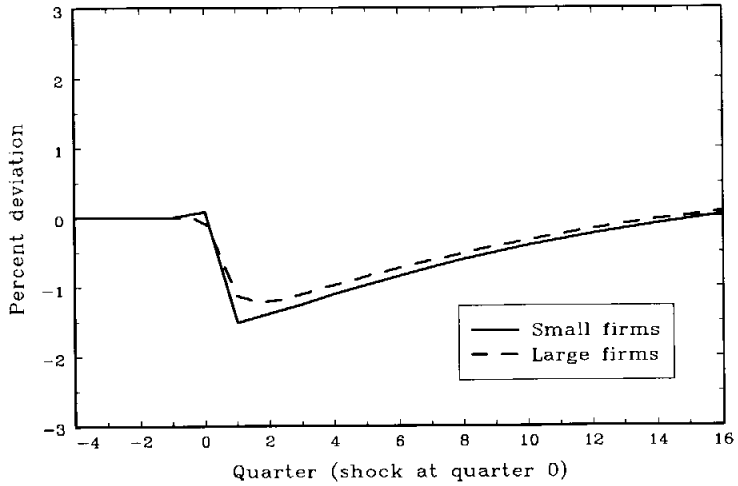

Figure 4c – Employment

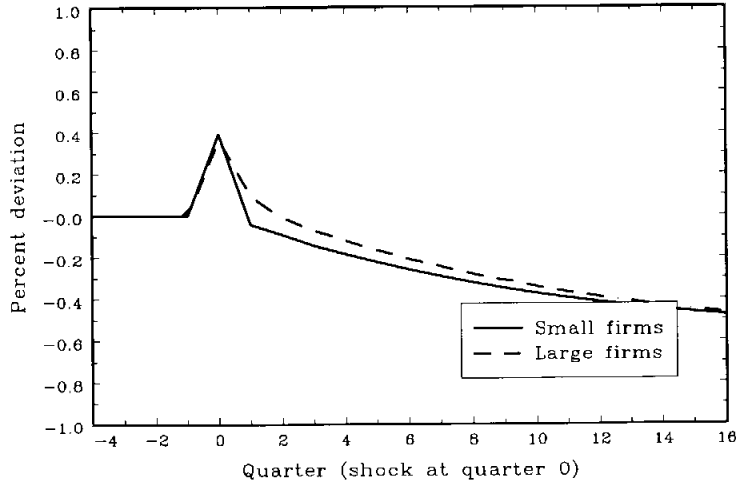

Figure 4d – Production

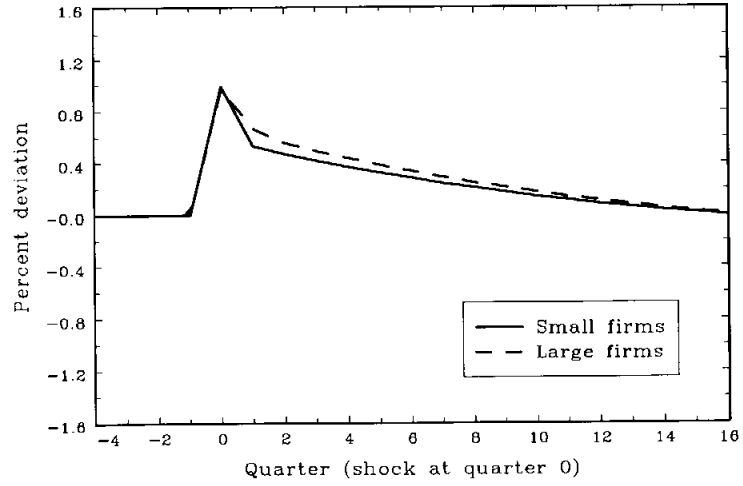

Figure 5a – Money shock: Output

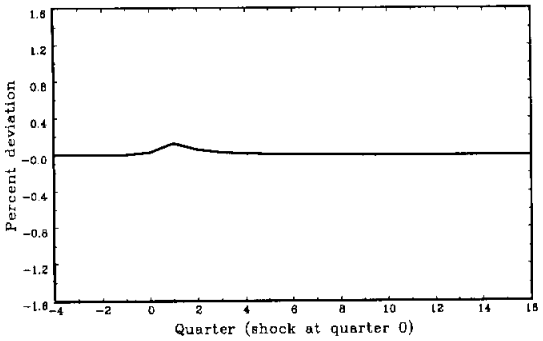

Figure 6a – Real Shock: Output

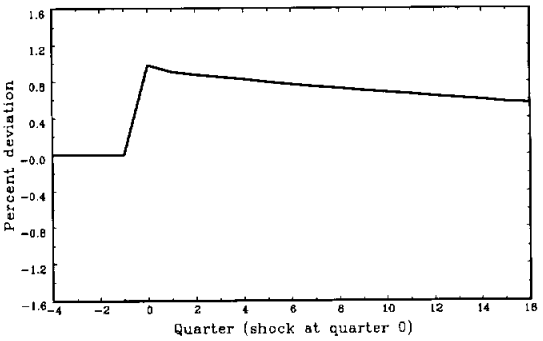

Figure 5b – Money shock: Hours

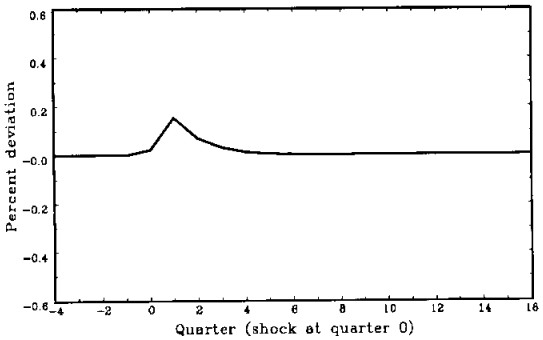

Figure 6b – Real shock: Hours

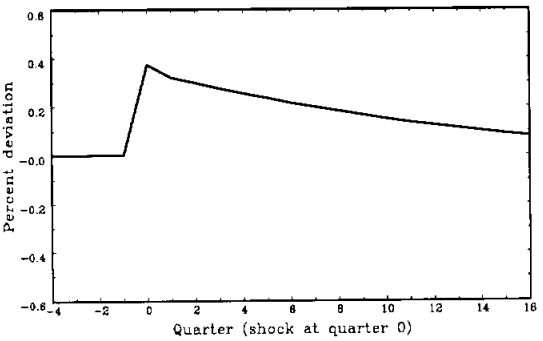

Figure 5c – Money shock: Wages

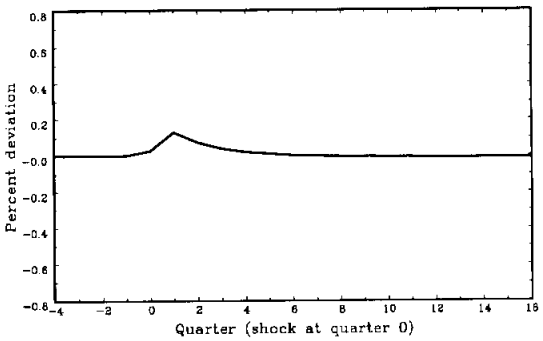

Figure 6c – Real shock: Wages

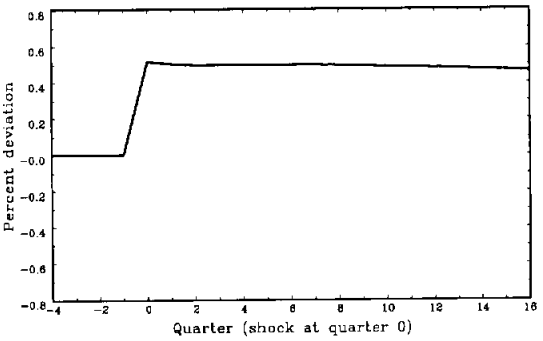

Figure 5d – Money shock: Profits

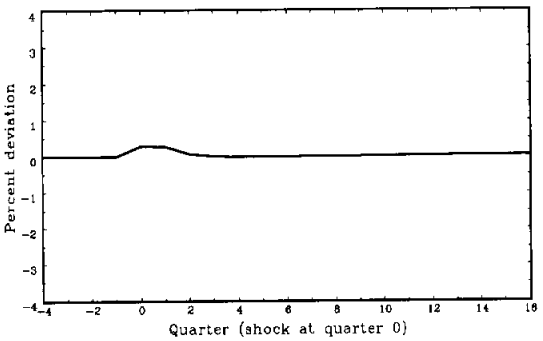

Figure 6d – Real shock: Profits

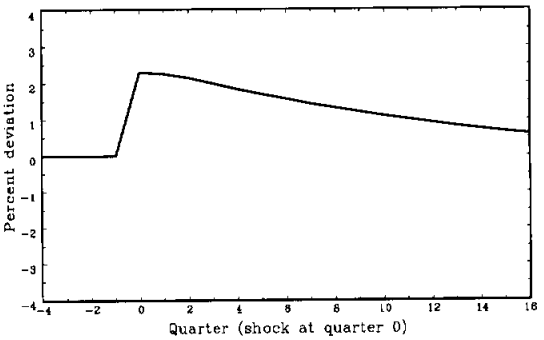

Figure 5e – Money shock: Interest on loans

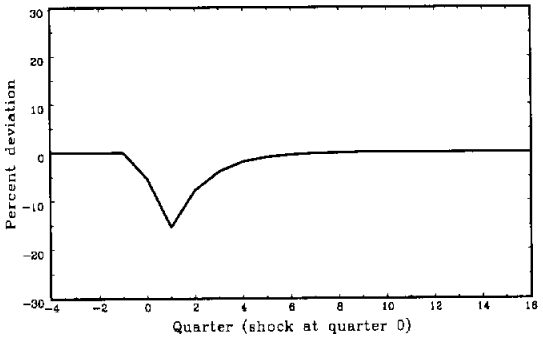

Figure 6e – Real Shock: Interest on loans

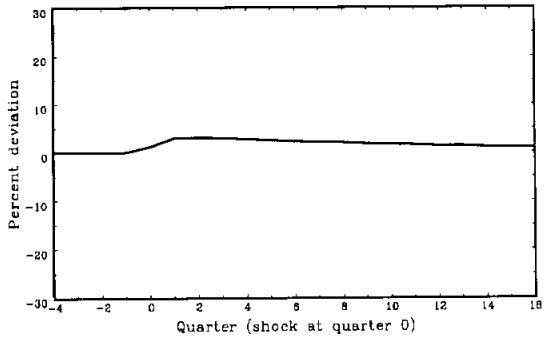

Figure 5f – Money shock: Nominal price

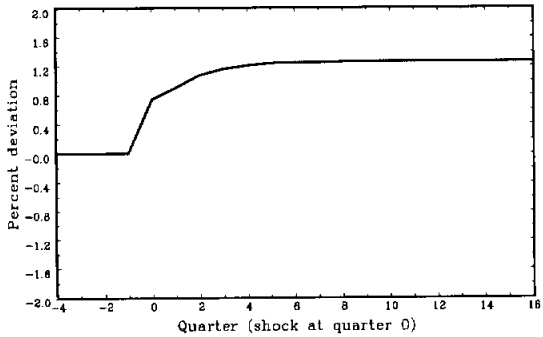

Figure 6f – Real shock: Nominal price

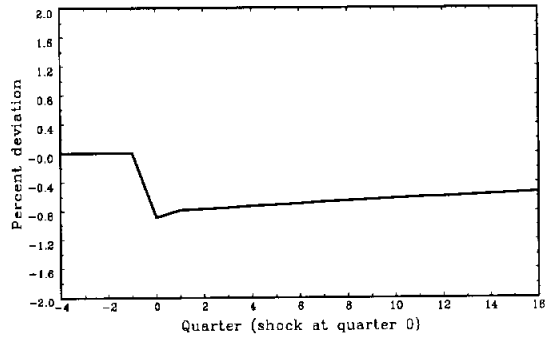

Figure 5g – Money shock: Exit rate

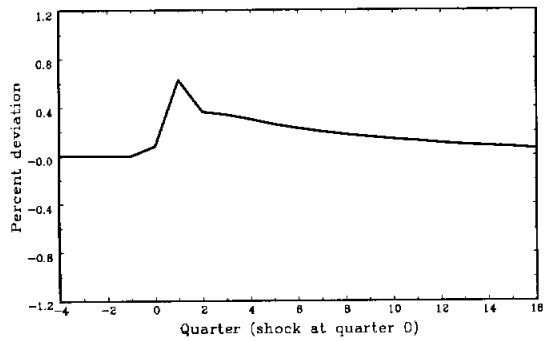

Figure 6g – Real shock: Exit rate

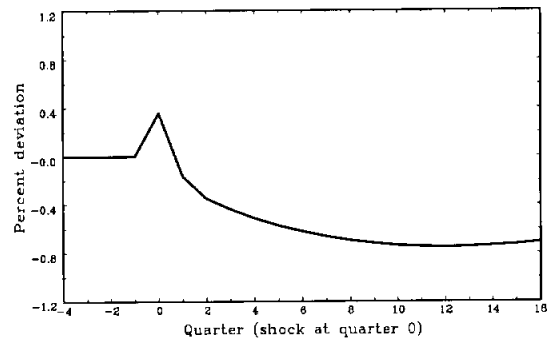

Figure 5h – Money shock: Entrance rate

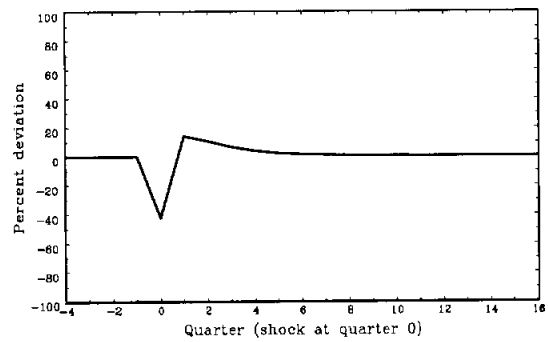

Figure 6h – Real shock: Entrance rate

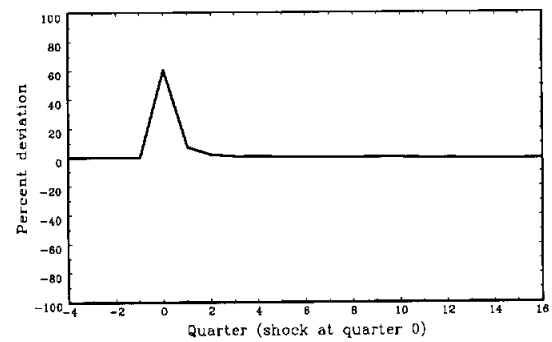

Figure 7a – Money shock: Stock index value

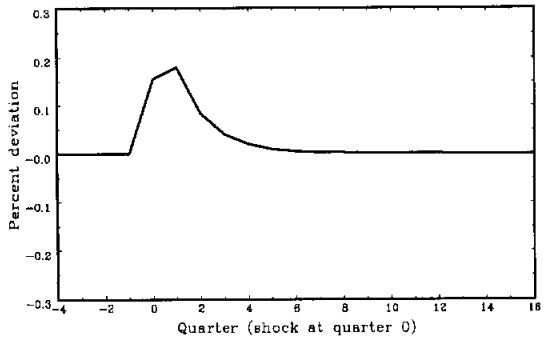

Figure 8a – Real shock: Stock index value

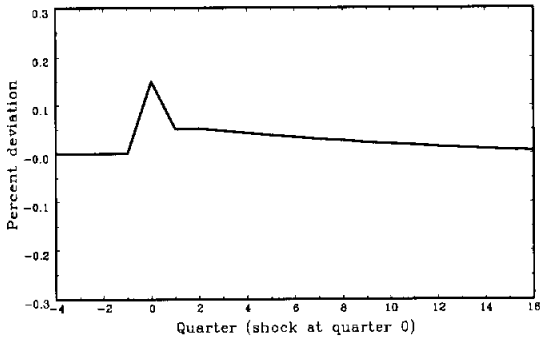

Figure 7b – Money shock: Stock index return

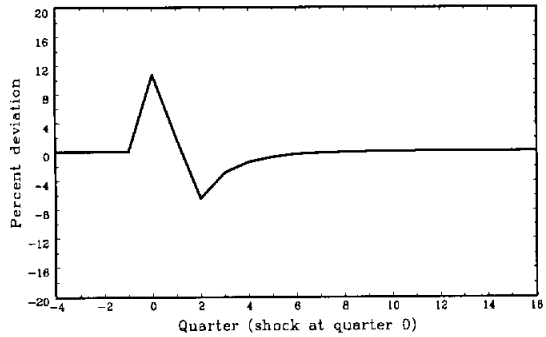

Figure 8b – Real shock: Stock index return

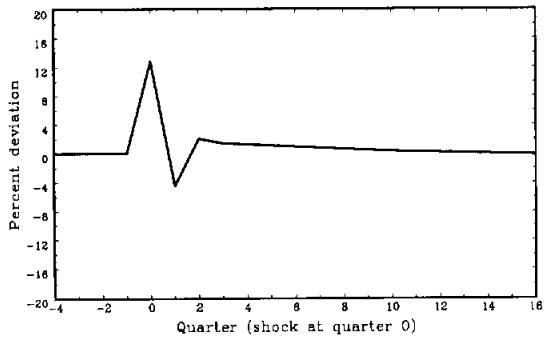

Figure 7c – Money shock: Stock index dividends

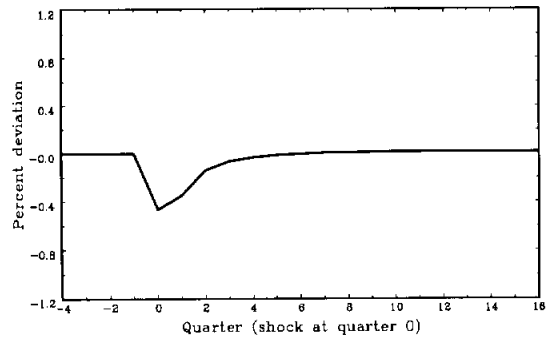

Figure 8c – Real shock: Stock index dividend

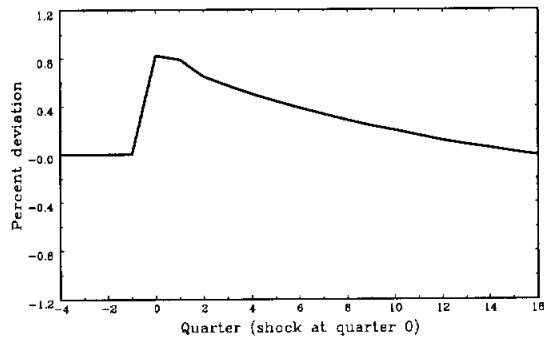

Figure 7d – Monetary shock: Total value

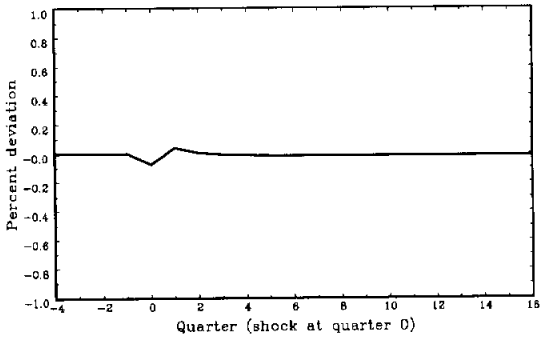

Figure 8d – Real shock: Total value

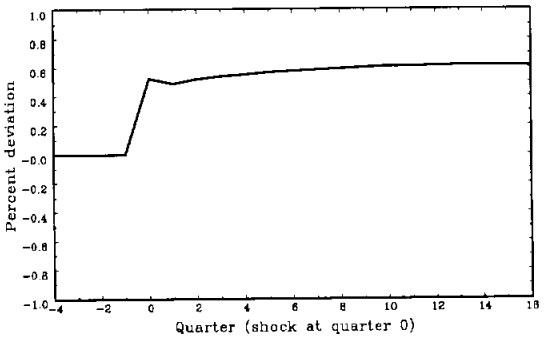

Figure 7e – Monetary shock: Total stock return

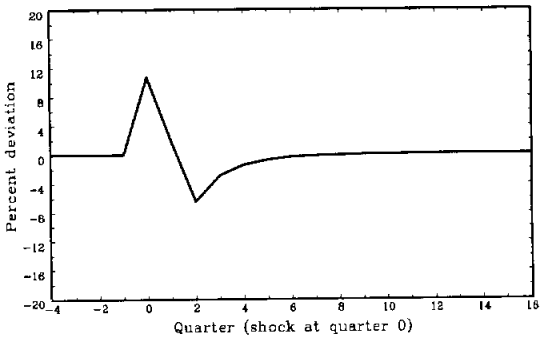

Figure 8e – Real shock: Total stock return

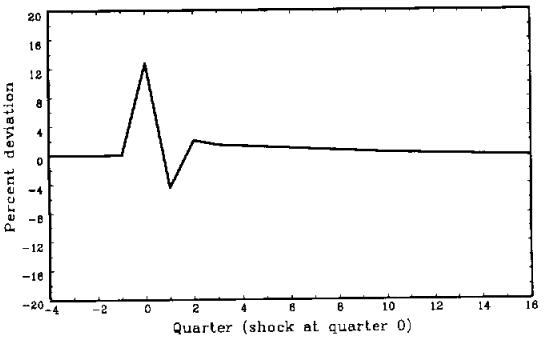

Figure 7f – Monetary shock: Total dividends

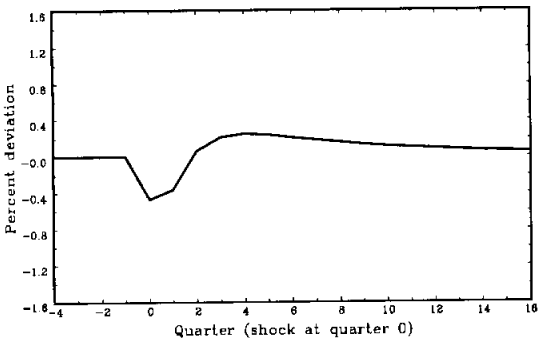
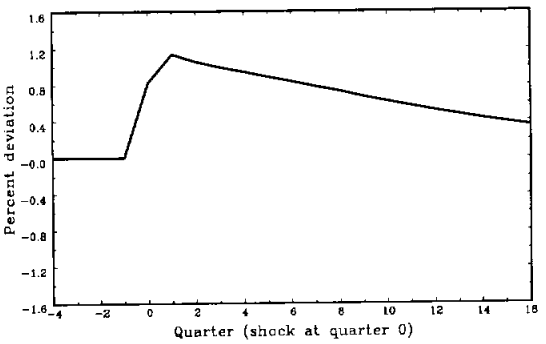
Figure 8f – Real Shock: Total dividends