

# Inflation, Investment Composition and Total Factor Productivity

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## Abstract

This paper argues that the empirically observed negative relationship between inflation and total factor productivity (TFP) can be understood on the basis of a dynamic stochastic general equilibrium model where causality runs from inflation to aggregate productivity. That is, TFP is not to be seen as an exogenous process, but as a function of economic variables which - among other things - are affected by the rate of inflation. We develop a theoretical model whose key ingredients are (i) a limited participation assumption which generates non-neutrality of monetary policy even under flexible prices, (ii) the scope for technology choice, and (iii) an agency problem which gives rise to financial market incompleteness. In this environment, we demonstrate how nominal fluctuations affect not only the overall amount, but also the composition of aggregate investment. Our calibrated benchmark economy is compared to alternative economies where either monetary shocks are absent or the steady state rate of inflation is changed; on the basis of this exercise we conclude that monetary policy shocks can account for a significant proportion of the variation in TFP. Finally, we substantiate the relevance of our basic hypothesis that nominal fluctuations affect the composition of aggregate investment by means of an empirical analysis of aggregate, sectoral and firm level panel data.

## 1 Introduction

The starting point for this paper is the empirical finding of a negative relation between inflation and total factor productivity (TFP), both at business cycle frequency and over longer horizons.<sup>1</sup> If one tries to give a causal interpretation to this correlation, one can pursue two ways, depending on the direction of causality that is stressed. Indeed, in standard monetary business cycle models featuring an exogenous productivity process and a quantity theory relation between money, output and prices, it is the case that - *ceteris paribus* - a negative productivity shock is associated with a higher rate of inflation. Hence, the premise in this class of models is a causal negative effect of TFP on inflation. However, given that TFP is taken to be a residual category which is not further modelled, this is an unsatisfactory situation; the reason is that we are left

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<sup>1</sup>A detailed assessment of the relevant empirical evidence will be provided in the subsequent sections.

with a "measure of our ignorance" (Abramovitz, 1956) in order to explain economic processes of first priority. Therefore, this paper takes a different route. While we do not question the merits of the aforementioned class of models for the purpose of studying macroeconomic dynamics or the effects of stabilization policies over the business cycle, we reverse the underlying notion of causality between inflation and TFP by stressing that the latter variable can be seen as a function of the former one. This implies that TFP is no longer an exogenous residual, but becomes an endogenous variable which is determined in the general equilibrium of our macroeconomic model.

Against this background, the present paper concentrates on the effect of monetary policy on TFP. Specifically, we argue that it is not appropriate to treat shocks to monetary policy and technology as orthogonal. The transmission mechanism that we put forward in order to rationalize the negative relationship between inflation and TFP is tied to the composition and effectiveness of aggregate investment. To formalize our argument, we develop a model economy whose underlying structure is based on the common point of departure of both modern business cycle and growth theory: the neoclassical growth model. This basic model is modified along three dimensions. *First*, it features a cash-in-advance (CIA) constraint and incorporates the assumption of limited asset market participation; this generates non-neutrality of monetary policy even in an environment with flexible prices via a liquidity effect. *Second*, the model does not involve a comprehensive aggregate production function, but starts from the presumption that investment can be channelled into two distinct technologies: a safe, but return-dominated ("basic") technology and a superior ("advanced") technology which yields higher expected returns, but is subject to idiosyncratic liquidity shocks. Firms operating the latter technology can insure themselves against such idiosyncratic risk by means of holding a precautionary stock of readily marketable assets; however, due to an entrepreneurial moral hazard problem, which is the *third* key building block of the model, the scope for insurance is limited. The consequence of this friction is that financial markets are incomplete in that scarce liquidity - along the lines of Holmstrom and Tirole (1998) - cannot be efficiently provided to the productive sector. In particular, given that insurance against liquidity shocks is costly, variations in the costs of insurance generate a composition effect that is found to be associated with changes in TFP. In the model we put forward, it turns out that these costs are given by the nominal interest rate. Specifically, quite similar to its role with respect to the opportunity costs of consumption in a simple cash-in-advance model, the nominal interest rate constitutes an additional cost of production by means of the advanced technology relative to the basic one. Hence, the model postulates a novel aspect of monetary transmission in that movements in the nominal interest rate are associated with changes in the composition of investment in the two available technologies.

In view of above arguments, it is evident that the present paper stands between business cycle and growth theory: It considers monetary and technological shocks as well as their interaction with a specific financial markets friction, but at the same time endogenizes the productivity process via an endogenous technology choice which is catalyzed by this friction.<sup>2</sup> Since the in-

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<sup>2</sup>For a similar approach, compare the recent paper by Aghion et al. (2005) who paraphrase the situation as follows: *"The modern theory of business cycles gives a central position to productivity shocks and the role of financial markets in the propagation of these shocks; but it takes the entire productivity process as exogenous. The modern theory of growth, on the other hand, gives a central position to endogenous productivity growth and the role of financial markets in the growth process; but it focuses on trends, largely ignoring shocks and cycles."*

centive problem we posit gives rise to an endogenous form of financial market incompleteness, we can derive a set of implications of the constrained-efficient contracting scheme which governs the provision of liquidity to firms operating the advanced technology. These implications relate to the reaction of the productive sector to monetary policy shocks and to the way in which industry level characteristics affect specific industries' sensitivity to such shocks. In order to assess the quantitative relevance of the transmission mechanism as well as its empirical relevance, we adopt a twofold strategy: On the one hand, we interpret our model as a literal business cycle model and calibrate it to the US economy at quarterly frequency. The calibrated benchmark economy is then compared to alternative economies whose basic structure is identical, but where either technology shocks or the financial market friction are absent. Comparing the respective model-generated moments, we conclude that, by generating an investment-composition driven variation in TFP, monetary policy shocks can account for a significant proportion of macroeconomic fluctuations. On the other hand, we use aggregate data from the US national accounts together with sectoral and firm-level panel data to substantiate the empirical relevance of our basic hypothesis that nominal fluctuations affect the composition of aggregate investment. Anticipating results, the findings emerging from dynamic panel regressions at quarterly and yearly frequency provide robust evidence in favor of our theoretical propositions. In particular, higher inflation is significantly found to negatively affect TFP (-growth), whereby the exogeneity of inflation cannot be rejected; thus, there is evidence that the negative relation between inflation and TFP indeed is due to a causal effect. While this result pertains to aggregate level data, the subsequent analysis of sectoral and firm-level data provides evidence consistent with (i) the implications of constrained-efficient contracting with respect to the postulated agency problem, as well as (ii) the notion that corporate liquidity holdings are used as a precautionary buffer stock to insure investment into advanced technologies and that the scope of such insurance is negatively affected by the level of inflation.

The rest of the paper is organized as follows. The next section provides a review of the related literature as well as a brief synopsis of some relevant empirical evidence, before Section 3 describes the theoretical model as the basic structure to formulate our main hypotheses. Section 4 examines the statistical properties of the postulated benchmark economy as well as those of alternative economies. Then, Section 5 seeks to empirically corroborate our proposition that the composition of aggregate investment is crucially affected by the conditions of insuring projects via corporate liquidity holdings by means of an analysis of panel data at different levels of aggregation. A final section concludes.

## 2 Related literature

**Theoretical literature:** The general equilibrium model we will formulate in the next section is similar in spirit to the approach taken by Aghion et al. (2005) who examine how credit constraints affect the cyclical behavior of productivity-enhancing investment. To that end, the authors develop a simple growth model where investment can be sunk into two types of activities which differ in their respective time horizons: a short-term project, and a long-term project which enhances future productivity. Importantly then, aggregate productivity has both an exogenous and an endogenous component. The exogenous component is specified as in a conventional real business cycle model, whereas the endogenous component is driven by the

mass of long-term projects that have successfully been completed in the past. Survival of long-term projects is uncertain because they are subject to idiosyncratic liquidity shocks which - for reasons left unspecified - can only be imperfectly insured. In this setup, an opportunity cost effect makes the demand for long-term investment countercyclical, while credit constraints induce a countervailing liquidity risk effect and generally depress the level of long-term investment. Hence, under sufficiently tight credit constraints, there are two effects: First, aggregate investment is shifted towards short-term activities, and second, long-term investment becomes procyclical, thus amplifying the business cycle. Similarly, Angeletos (2006) studies the effects of idiosyncratic investment risk on the aggregate level and the allocation of savings within the framework of a non-monetary neoclassical growth model. Hence, unlike Bewley-type economies the model features capital rather than labor income risk. One model variant considers the aggregate dynamics resulting from the choice of investing either into privately-held projects or into public equity, which allows to pool idiosyncratic risks. The key implication then is that, quite similar to what will happen in the model economy developed below, incomplete markets reduce TFP by shifting resources away from the more risky, but also more productive private equity investment.

One disadvantage with above approaches is that their implications for the economy's cyclical dynamics critically hinge on the *assumption* that uninsured idiosyncratic investment risk evolves in a countercyclical fashion. In order to improve along this dimension, it is important to carefully specify the source of market incompleteness which gives rise to uninsured idiosyncratic risk. In our study, we will do so by embedding the contracting problem discussed in Holmstrom and Tirole (1998) into a business cycle model.<sup>3</sup> The question addressed there is whether private claims provide enough liquidity to guarantee the efficient functioning of the productive sector. In contrast to the classical theory of finance, where there is no corporate demand for liquidity since firms, at any time, can issue claims up to the full present value of their expected future returns, the paper introduces an entrepreneurial moral hazard problem that creates a demand for liquidity in the form of advance financing. If this corporate demand for liquidity is matched with an endogenous supply of funds, the key observation to be drawn is that the same agency problem that limits the scope for ex post refinancing also limits the amount of resources that can be raised for investment purposes ex ante. Moreover, variations in the liquidity premium will endogenously affect the degree of market incompleteness and thus the composition of aggregate investment.

The models mentioned above are all based on real economies, but starting from the contributions by Bernanke and Gertler (1989, 1995) there is also an extensive literature dealing with the interaction of financial market frictions and the monetary transmission process. Rather

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<sup>3</sup>Kato (2006) adopts a similar approach, but in a real one-sector model. Meh and Quadrini (2006) consider a model with endogenous market incompleteness with respect to individual investment risk. A different agency problem is studied in Rampini (2004) who analyzes an economy where entrepreneurs face a choice between a safe project and a risky project which is more productive in expectation. For incentive reasons, agents who take the risky project need to bear part of the idiosyncratic risk. The agents' risk aversion implies that they are willing to bear more risk when productivity is high; additionally, their incentive constraint is relaxed such that they need to bear less risk during a boom. The consequence of such countercyclical agency costs is that entrepreneurial activity is procyclical. Hence, technology shocks are amplified, and there results a first-order effect on aggregate output. The reason is that at a point where an agent is indifferent between the riskless and the risky project, the expected output of the risky project exceeds the return of the riskless project since the agent has to be compensated for taking risk.

than reviewing this literature, we point to a particular model whose underlying structure is quite similar to our own setup: Cooley and Quadrini (2006) develop a general equilibrium model with heterogeneous, long-lived firms facing an exogenous borrowing constraint. All firms have access to the same decreasing returns to scale technology, whereby production is financed with external funds borrowed from a financial intermediary. Since these funds have to be paid in advance, the model captures the so-called cost channel of monetary transmission.<sup>4</sup> The paper's focus is on industry dynamics and on the financial decisions of heterogeneous firms which differ in the amount of equity they have accumulated in the past as well as the idiosyncratic productivity shock they receive in the current period. The model's key implications relate to the overall amount of investment as well as to its cross-sectional distribution across firms and to its dynamics rather than to the composition of investment: A fall in the nominal interest rate decreases the interest payments of firms on short-term loans and increases their profits.<sup>5</sup> Because of reinvested profits, any operating firm's financial capacity is increased in the next period, and this allows to expand production. For small firms, it is more important to expand the future capacity, while large firms are more concerned about the volatility of profits. This implies that small firms are more highly leveraged in equilibrium, and hence, above transmission mechanism is more important for small firms. Moreover, since a monetary shock affects the amount of equity held by firms in the next period, there results a propagation mechanism which gives rise to a persistent response of macroeconomic aggregates to interest rate shocks.

**Empirical literature and evidence:** In the field of business cycle research, there exists an extensive literature on the transmission of monetary (policy) shocks. We make no attempt to review this branch of the literature, but refer the reader to the work by Christiano, Eichenbaum and Evans (1997, 2005) and others. Similarly, we largely neglect the literature on economic growth which employs low frequency data and cross-country panel regressions to investigate the nexus between inflation and growth.<sup>6</sup> Rather, in line with the present paper's focus, we organize our reading of the relevant empirical work in two steps: First, we selectively draw on the literature to provide evidence (i) on the relationship between inflation on the one hand and growth and aggregate productivity on the other hand, as well as (ii) on the linkage between inflation and aggregate investment. Second, we resort to evidence from disaggregate firm level data which provides valuable background information with respect to our proposed transmission mechanism.

Applying cross-sectional and panel growth regressions for yearly data, Fischer (1993) finds a negative correlation between inflation and growth, which is traced back to the effects of the inflation tax and increased uncertainty.<sup>7</sup> He investigates the causal mechanism behind this correlation in several ways, arguing that an empirical discrimination between level and

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<sup>4</sup>See Barth and Ramey (2001) for an empirical account.

<sup>5</sup>See Lucas (1990) as well as Christiano and Eichenbaum (1992, 1995) for contributions developing general equilibrium models characterized by limited asset market participation and liquidity effects of monetary policy.

<sup>6</sup>Important contributions in this branch of research include De Gregorio (1992, 1993), Barro (1996), Bruno and Easterly (1998) and Easterly (2005).

<sup>7</sup>Fisher offers three potential mechanisms to rationalize the negative relationship: (i) a reduction in productivity growth because of distortions in the informational content of the price level due to aggregate uncertainty; (ii) a reduction in capital accumulation stemming from temporary hold up of investment decisions in the presence of aggregate uncertainty; (iii) the inflation tax on returns from capital and R&D investment if investors must hold cash-in-advance.

uncertainty effects of inflation is hardly possible since both measures are highly correlated, and that adverse supply shocks are an important source for the endogeneity of inflation.<sup>8</sup> To assess the relevance of non-linearities, Fisher uses splines (with breakpoints at 15% and 40%) and finds the negative correlation between inflation and TFP-growth to be, if anything, larger in low-inflation (OECD-)countries. Moreover, the author decomposes GDP growth into its components and detects a robust negative relation between inflation on the one hand and the growth rate of capital, but also of TFP on the other hand. This last result implies that, even after controlling for factor accumulation and employment, the negative effect of inflation on growth persists; that is, there must be some inflation-driven mechanism which records in terms of decreased aggregate productivity.

The study by Ramey and Ramey (1995)<sup>9</sup> establishes a negative correlation between the level of macroeconomic volatility and the trend of GDP growth; this finding is robust to the inclusion of the investment share of GDP. Interestingly, Ramey and Ramey are not able to find a robust empirical relationship between inflation and the share of aggregate investment in GDP. Furthermore, by considering deviations from a forecasting equation, they are able to show that most of the volatility-growth correlation is due to variations in unexpected innovations to GDP growth. Hence, their results suggest that uncertainty induced by nominal or real innovations is an important factor to link volatility and growth, while the importance of aggregate investment is called into question. In particular, we note that their empirical findings are inconsistent with the notion of an AK-model à la Romer (1990), where the transmission to an economy's growth performance would be via aggregate investment.

Aghion et al. (2005) elaborate on this issue and use country-level panel data to assess the empirical implications of their theoretical model with respect to the investment-driven relationship between volatility and growth. In their analysis, the authors focus on the composition rather than on the level of aggregate investment for two reasons: First, as established by Ramey and Ramey, the negative impact of volatility on growth persists even after one controls for the level of aggregate investment; and second, the correlation between volatility and growth may be spurious because, in fact, variations in both variables may be due to differences in financial development. To operationalize their analysis of the composition of aggregate investment, the authors use data on R&D expenditures to approximate investment in superior technologies,<sup>10</sup> whereas investment in safer, return-dominated technologies is approximated by total investment as a fraction of GDP. The evidence generated via dynamic panel estimations is that exogenous shocks negatively influence the R&D share, while the aggregate investment share remains unaffected. This result hints at the importance of composition effects in investment rather than movements in total investment to account for the impact of volatility on economic growth and the characteristics of the business cycle.

Our own study starts from the results in Aghion et al. (2005) and seeks to analyze how

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<sup>8</sup>The difficulty in identifying a causal relation between inflation and growth stems from the lack of appropriate external instruments for inflation. For cross-country regressions, a possible instrumental variable approach is due to Cukierman et al. (1993) who incorporate measures of central bank independence as instrumental variables and detect negative correlations with economic growth. Our own approach circumvents the problem by applying dynamic panel regressions, thus relying on internal instruments whose validity is testable.

<sup>9</sup>The authors apply cross section and (static) panel estimations covering the period 1960-1985 for a sample of 92 countries and subset of 24 OECD-countries.

<sup>10</sup>Walde and Woitek (2004) provide evidence on the *level* of R&D expenditure, which tends to be procyclical; conversely, Aghion et al. (2005) focus on the cyclical variation of R&D as a *share* of total investment.

nominal fluctuations impact on firms' investment decisions. The structure of the model we develop in the next section suggests that the availability of corporate liquidity is a crucial determinant for these firm-level investment decisions. To get some guidance on the potential power of this mechanism, we relate our analysis to the findings in Opler et al. (1999) who examine the determinants and implications of holdings of cash and marketable securities by publicly traded non-financial US firms. The authors establish that firms with better outside financing opportunities<sup>11</sup> tend to hold a lower fraction of their total assets in the form liquid assets, and that firms with strong growth opportunities and riskier cash flows hold relatively high ratios of cash to total non-cash assets.<sup>12</sup> Moreover, there is evidence that firms retain a relatively high fraction of their earnings as liquid reserves and that these reserves are generally not used for capital investment, but rather tend to be depleted by operating losses. As to the quantitative importance of corporate cash holdings, the authors report the mean over the firms in their sample of the ratio of cash to net assets to be 17%, while the median amounts to 6.5%. Thus, corporate liquidity holdings are likely to constitute a relevant category; in what follows we will elaborate on this hypothesis.

### 3 The model

In this section, we propose a monetary model of a closed economy characterized by limited asset market participation and subject to a financial markets friction. The economy is populated by two sets of agents, households and entrepreneurs, each of unit mass. Moreover, there are a financial intermediation sector and a productive sector, organized in decentralized firms, which has access to two distinct technologies, labelled "basic" and "advanced" for reasons that will become apparent in the sequel.<sup>13</sup> Finally, there is a government ("monetary authority") which implements macroeconomic policies. These policies, together with a set of exogenous shocks, expose the economy to aggregate uncertainty. The timing structure underlying our model is as follows. Time is discrete, and within each period  $t$ , there are three points in time: one at the beginning of the period, denoted  $t^-$ , one at an interim stage when the vector  $s_t$  of aggregate shocks materializes and information about them is revealed, and finally one at the end of the period, denoted  $t^+$ . The aggregate shocks in our model are productivity shocks  $\mathcal{A}_t$ ,  $\mathcal{V}_t$  to the two technologies as well as to government policy  $\mathcal{J}_t$  (to be specified later); hence, we have  $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$ . Apart from these aggregate shocks, there are purely idiosyncratic liquidity shocks  $\xi_t^i$  to the subset of firms operating the advanced technology. We now turn to a detailed description of the environment in which the economy's agents interact and define their relevant decision problems as well as the relevant concept of a competitive equilibrium.

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<sup>11</sup>The background for most theoretical and empirical studies of corporate cash holdings is the presumption that external finance is costly and that firms hold liquid assets in order to survive bad times and to have funds readily available if an investment opportunity arises. The benefits of corporate liquidity must then be balanced against its costs which arises as a consequence of a liquidity premium.

<sup>12</sup>We interpret these latter characteristics - high growth potential and risky cash flows - as the identifying characteristics of what we label "advanced" technology.

<sup>13</sup>As a general rule, variables pertaining to the basic sector are indicated by the variable/superscript  $k$ , while  $z$  is the relevant indicator for the advanced sector.

### 3.1 Households

The economy is populated by a unit mass of infinitely-lived, risk averse households.<sup>14</sup> Households enter a given period  $t$  with claims to two distinct capital stocks  $(k_t, z_t)$  accumulated from the past together with a nominal wealth position  $M_t$ . At time  $t^-$ , households divide their nominal wealth into resources  $Q_t$  disposable for consumption later in the period and deposits  $M_t - Q_t$  with a financial intermediary that earn a net interest rate  $(\tilde{R}_t - 1)$ .<sup>15</sup> After aggregate shocks have unfolded, households rent out their sector-specific physical capital to the firms operating the basic and advanced technology, respectively. Similarly, they supply labor  $h_t^k$  to the basic sector and  $h_t^z$  to the advanced sector, and their aggregate labor supply is  $h_t^H = h_t^{k,H} + h_t^{z,H}$ , whereby households are indifferent as to the sectoral composition of their labor supply. At time  $t^+$ , households receive the returns from labor and capital and make consumption and investment decisions. However, there is a cash constraint on the goods market with the consequence that the household's current expenditure for consumption  $c_t^H$  and physical investment  $x_t$  must be covered by the resources  $Q_t$  earmarked for consumption plus a fraction  $\theta$  of his current wage earnings. The household has preferences over sequences of consumption and labor supply; hence, the household problem is to maximize lifetime utility:

$$E_{0-} \sum_{t=0}^{\infty} \beta^t u(c_t^H, h_t^H) \quad (1a)$$

subject to the cash constraint:

$$Q_t + \theta[W_t^{k,H} h_t^{k,H} + W_t^{z,H} h_t^{z,H}] \geq P_t[c_t^H + x_t], \quad (1b)$$

an equation describing the evolution of nominal assets:

$$\begin{aligned} M_{t+1} &= Q_t + \theta[W_t^k h_t^{k,H} + W_t^z h_t^{z,H}] - P_t[c_t^H + x_t] + \tilde{R}_t[M_t - Q_t + \mathcal{J}_t] \\ &+ \Upsilon_t + R_t^k k_t + R_t^z z_t + (1 - \theta)[W_t^{k,H} h_t^{k,H} + W_t^{z,H} h_t^{z,H}], \end{aligned} \quad (1c)$$

where  $\mathcal{J}_t$  are cash injections into the financial market on behalf of the government and  $\Upsilon_t$  are nominal resources redistributed in a lump sum fashion among the consumers at the end of the period, and subject to a law of motion for aggregate capital  $K_t = k_t + z_t$ , which accounts for depreciation and sector-specific adjustment costs:

$$x_t = (k_{t+1} + z_{t+1}) - (1 - \delta)(k_t + z_t) + \Phi(k_t, k_{t+1}) + \Phi(z_t, z_{t+1}) \quad (1d)$$

The solution to the household problem can be summarized by a set of optimality conditions which characterize the household's equilibrium behavior. The first one is the Euler equation describing the optimal intertemporal allocation of nominal wealth:

$$E_{t-} \left\{ \frac{u_c(c_t^H, h_t^H)}{P_t} - \beta \tilde{R}_t \frac{u_c(c_{t+1}^H, h_{t+1}^H)}{P_{t+1}} \right\} = 0 \quad (2)$$

<sup>14</sup>Where necessary, variables pertaining to the household sector will be denoted with a superscript  $H$ .

<sup>15</sup>This timing convention is standard in monetary models which feature a limited participation assumption on the household side; compare e.g. Lucas (1990). Our timing convention necessitates a careful treatment of the information sets relevant to the household when it takes decisions. Specifically, there is a distinction between expectation operators at the beginning of a period (time  $t^-$ ) and at the end of a period (time  $t^+$ ).

Next, there are two Euler equations which determine the sequence of dynamic decisions between consumption and sector-specific investments; for  $i = k, z$ , they read:

$$u_c(c_t^H, h_t^H) [1 + \Phi_2(i_t, i_{t+1})] = \beta E_t \left\{ u_c(c_{t+1}^H, h_{t+1}^H) [(1 - \delta) - \Phi_1(i_{t+1}, i_{t+2})] + \beta \frac{u_c(c_{t+2}^H, h_{t+2}^H)}{P_{t+2}} R_{t+1}^i \right\} \quad (3)$$

An immediate implication of the two equations (3) is that the sector-specific interest rates must be equal in expectation, i.e.  $E_t\{R_{t+1}^k\} = E_t\{R_{t+1}^z\} = E_t\{R_{t+1}\}$ . Similarly, there are two optimality conditions which govern the household's consumption-leisure choice, thus determining the optimal supply of labor to either sector  $i = k, z$ :

$$u_h(c_t^H, h_t^H) + \left[ \theta \frac{u_c(c_t^H, h_t^H)}{P_t} + (1 - \theta) \beta E_t \left\{ \frac{u_c(c_{t+1}^H, h_{t+1}^H)}{P_{t+1}} \right\} \right] W_t^{i,H} = 0 \quad (4)$$

Here, it follows that, in all states of the world, the sectoral wage rates must be identical because the household cares only about aggregate labor supply; hence, we have  $W_t^{k,H} = W_t^{z,H} = W_t^H$ .

### 3.2 Entrepreneurs

Apart from households, there is a unit mass of risk neutral entrepreneurs, each one capable of running a specific project associated with the advanced production technology.<sup>16</sup> At the beginning of each period, a mass  $(1 - \eta)$  of new-born entrepreneurs enters the economy without any initial wealth and replaces an equal measure of retiring entrepreneurs. The remaining measure  $\eta$  of incumbent entrepreneurs stays active. An individual entrepreneur arrives in period  $t$  with an amount  $A_t^i$  of nominal wealth. Then, if she receives a random exit signal, she waits until the end of the period to simply consume her accumulated wealth such that  $A_t^i = P_t c_t^{E,i}$ . In contrast, new entrants and entrepreneurs who have not received the exit signal have no consumption motive; rather, each active entrepreneur inelastically supplies her (unit) labor endowment  $h_t^E = h_t^{k,E} + h_t^{z,E} = 1$  and thus augments her nominal wealth  $A_t^i$  by her current wage earnings  $W_t^E$ . As for consumers, only a fraction  $\theta$  of these wage earning is immediately disposable such that an individual entrepreneur's effective wealth position is  $E_t^i = A_t^i + \theta W_t^E$ . This position  $E_t^i$  constitutes the entrepreneur's necessary private equity stake when she applies for funding of an advanced sector project with the financial intermediary.

### 3.3 Financial intermediary

The financial intermediary (equivalently, a perfectly competitive financial sector) receives the time  $t^-$  financial deposits  $M_t - Q_t$  from the households as well as lump sum cash injections  $\mathcal{J}_t$  from the monetary authority. These funds are supplied to the loan market at a gross nominal interest rate  $\hat{R}_t$ . At the loan market, this supply meets the demand for financial assets which comes from two sources: First, both sectors' firms demand short term credit in order to meet the advance financing requirement for a fraction  $\theta$  of their respective wage bills ( $W_t$  is the relevant aggregate wage rate, reflecting both the wage  $W_t^H$  received by households and the

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<sup>16</sup>Where necessary, variables pertaining to the entrepreneurial sector will be denoted with a superscript  $E$ .

wage  $W_t^E$  received by entrepreneurs). Second, there is a demand for liquidity  $D_t$  coming from firms operating the advanced technology. Hence, financial market clearing requires:

$$M_t - Q_t + \mathcal{J}_t = \theta W_t L_t + D_t \quad (5)$$

This condition simply stipulates that the equilibrium interest rate  $\tilde{R}_t$  balances the supply of loans with the corporate demand for funds due to its advance financing requirement and its need for liquidity. The financial intermediary operates after aggregate uncertainty is resolved. While lending to basic sector firms proceeds in a frictionless market, lending to advanced sector firms is complicated by an entrepreneurial moral hazard problem which is dealt with by a financial contract described in Section 3.5. Two key implications of that contracting scheme are that firm bankruptcy is an equilibrium phenomenon and that the intermediary must commit funds to individual advanced sector projects before these projects' respective liquidity needs are known. Therefore, it is important to recognize that the financial intermediary is able to pool idiosyncratic risks across the advanced sector firms because, as a consequence, it is sufficient for the financial intermediary to break even on an individual credit relationship in expectation. At the end of the period, the intermediary receives the returns on its lending and financial investment activity and pays the amount  $\tilde{R}_t[M_t - Q_t + \mathcal{J}_t]$  to the households in return for their deposits.

### 3.4 Firms

In our economy, production activities proceed in three types of firms. The first type produces the final market good that can be used either for consumption or investment purposes. Firms supplying the market good use an aggregation technology with two intermediate input goods which are produced by the two other types of firms operating in the basic and advanced sector, respectively. In all three goods markets, firms face perfect competition.

#### 3.4.1 Market good

The market good producers employ the following CES aggregation technology:

$$y_t = \left( \zeta^{\frac{1}{\rho}} y_t^k{}^{\frac{\rho-1}{\rho}} + (1 - \zeta)^{\frac{1}{\rho}} y_t^z{}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}, \quad (6)$$

where  $y_t$  is the final output good and  $y_t^z$  and  $y_t^k$  are the two intermediate input goods. The two parameters  $0 < \zeta < 1$  and  $\rho > 0$  determine the share of each intermediate good in producing the aggregate market good and the elasticity of substitution of the two factors. Productive efficiency pins down the minimum cost combination of the final good firms' demands for intermediate input goods to be functions of the relative prices for the relevant intermediate input  $P_t^j$ ,  $j = k, z$  and for the final output  $P_t$ :

$$y_t^k = \zeta \left( \frac{P_t^k}{P_t} \right)^{-\rho} y_t \quad \text{and} \quad y_t^z = (1 - \zeta) \left( \frac{P_t^z}{P_t} \right)^{-\rho} y_t \quad (7)$$

By perfect competition on the final goods market, the aggregate price level is determined by marginal costs, i.e. the intermediate good prices, which are constant from the final good firm's

perspective. Consequently, zero profits imply:

$$P_t = \left( \zeta P_t^{k^{1-\rho}} + (1-\zeta) P_t^{z^{1-\rho}} \right)^{\frac{1}{1-\rho}} \quad (8)$$

For future reference, we also define the elasticities of aggregate output with respect to the sectoral intermediate output levels:

$$\omega_{yk,t}^y \equiv \frac{dy_t/y_t}{dy_t^k/y_t^k} = \zeta^{\frac{1}{\rho}} \left( \frac{y_t^k}{y_t} \right)^{\frac{\rho-1}{\rho}} \quad \text{and} \quad \omega_{yz,t}^y \equiv \frac{dy_t/y_t}{dy_t^z/y_t^z} = (1-\zeta)^{\frac{1}{\rho}} \left( \frac{y_t^z}{y_t} \right)^{\frac{\rho-1}{\rho}} \quad (9)$$

### 3.4.2 Intermediate goods

There are two perfectly competitive sectors producing intermediate goods. Both sectors employ capital as well as labor as input goods, but are characterized by different technologies. On the one hand, there is a safe, but return-dominated ("basic") technology; the other ("advanced") technology yields a higher potential return, but is subject to idiosyncratic liquidity shocks. The scope for an individual advanced firm's insurance against this idiosyncratic liquidity risk is endogenously determined via the financial contract described in Section 3.5. The need for this insurance arises as a consequence of an entrepreneurial moral hazard problem prevents the efficient refinancing of projects and calls for the commitment of liquidity at an ex ante, rather than an ex post stage. The other friction that is relevant for both types of intermediate firms is an advance payment requirement, which necessitates the firms' borrowing working capital in order to be able to pay wages; the parameter  $\theta \in [0, 1]$  represents the fraction of the outlays that needs to be financed in advance.

**Basic sector:** Firms in the basic sector seek to maximize time  $t^+$  profits by hiring labor and capital inputs  $\{l_t^k, k_t\}$ , whereby the vector of prices  $\{P_t^k, W_t^k, R_t^k, \tilde{R}_t\}$  is taken as given. A Cobb-Douglas aggregator converts household and entrepreneurial labor inputs into their effective composite, and similarly agent-specific wages aggregate to a sectoral wage rate:

$$l_t^k = \frac{(h_t^{k,H})^\Omega (h_t^{k,E})^{(1-\Omega)}}{(\Omega)^\Omega (1-\Omega)^{(1-\Omega)}} \quad \text{and} \quad W_t^k = (W_t^{k,H})^\Omega (W_t^{k,E})^{(1-\Omega)}$$

The technology characterizing the basic intermediate sector is assumed to be homogenous of degree one and features labor augmenting technological progress at the exogenous rate  $\gamma$ . For simplicity, we employ the Cobb-Douglas form:

$$\varphi(k_t, l_t^k) = (k_t)^{\alpha^k} \left( (1+\gamma)^t l_t^k \right)^{1-\alpha^k}$$

Hence, the problem of a representative firm operating the basic technology is:

$$\begin{aligned} \max_{\{k_t, l_t^k\}} \Pi_t^k &= P_t^k (\mathcal{A}_t \varphi(k_t, l_t^k)) - W_t^k l_t^k - R_t^k k_{t-1} - \theta(\tilde{R}_t - 1) W_t^k l_t^k \\ &= P_t^k y_t^k - C(W_t^k, R_t^k, \tilde{R}_t; y_t^k) \end{aligned} \quad (10)$$

By constant returns to scale, efficient factor employment implies that marginal costs are independent of the quantity produced, i.e.  $C(W_t^k, R_t^k, \tilde{R}_t; y_t^k) = MC_t^k(W_t^k, R_t^k, \tilde{R}_t; 1) y_t^k$ . Then, from

the assumption of perfectly competitive intermediate goods markets, it follows that the price of the basic intermediate good equals marginal costs, i.e.  $P_t^k = MC_t^k(W_t^k, R_t^k, \tilde{R}_t)$ . Using the Cobb-Douglas specification of  $\varphi(k_t, l_t^k)$ , the optimal factor demands in the basic sector read:

$$k_t = \frac{\alpha^k P_t^k y_t^k}{R_t^k} \quad \text{and} \quad l_t^k = \frac{(1 - \alpha^k) P_t^k y_t^k}{[1 + \theta(\tilde{R}_t - 1)] W_t^k} \quad (11)$$

Finally, the price for the basic intermediate good is:

$$P_t^k = \frac{1}{\mathcal{A}_t} \left( \frac{R_t^k}{\alpha^k} \right)^{\alpha^k} \left( \frac{[1 + \theta(\tilde{R}_t - 1)] W_t^k}{(1 - \alpha^k)} \right)^{(1 - \alpha^k)} \quad (12)$$

**Advanced sector:** The problem of firms operating the advanced technology is complicated by the risk that their production plan is hit by a liquidity shock<sup>17</sup> which may trigger the termination of projects before they yield any return. As in the basic sector, there is a Cobb-Douglas aggregation of the respective labor inputs by households and entrepreneurs, and the technology in the advanced sector is given by a Cobb-Douglas production function under constant returns to scale which allows for exogenous labor augmenting technological progress:

$$f(z_t, l_t^z) = (z_t)^{\alpha^z} ((1 + \gamma)^t l_t^z)^{1 - \alpha^z}$$

Each advanced firm is run by an individual entrepreneur who brings the amount  $E_t^i$  as private equity into the firm. The firm's production plan and its hedge against liquidity shocks  $\xi_t^i$ , which are distributed according to a continuous distribution function  $G(\xi_t^i)$  with associated (strictly positive) density  $g(\xi_t^i)$ , are then determined as part of a constrained-efficient contract between the entrepreneur and the financial intermediary. In particular, the liquidity provision stipulated by the financial contract will be seen to pin down a threshold value  $\hat{\xi}_t^*$  up to which liquidity shocks are covered; this threshold, in turn, determines an individual advanced firm's ex ante survival probability  $G(\hat{\xi}_t^*)$ . Since the financial contract, derived in Section 3.5, turns out to be linear in  $E_t^i$ , the distribution of equity across entrepreneurs does not matter and exact aggregation is possible.<sup>18</sup> Hence, we anticipate results and note in analogy to the basic sector that the price level for the intermediate goods produced in the advanced sector is:

$$P_t^z = \frac{1}{\tilde{R}_t \int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t} \frac{1}{\mathcal{V}_t} \left( \frac{R_t^z}{\alpha^z} \right)^{\alpha^z} \left( \frac{[1 + \theta(\tilde{R}_t - 1)] W_t^z}{(1 - \alpha^z)} \right)^{(1 - \alpha^z)} \quad (13)$$

The details of the financial contract are described in the next section.

<sup>17</sup>The liquidity shock admits a variety of interpretations. It can be thought of as a simple cost overrun, as a shortfall of revenue at an interim stage which could have been used as an internal source of refinancing or as adverse information relating to the project's end-of-period profitability. Hence, we stress that our notion of liquidity shock is consistent with what Opler et al. (1999) empirically summarize under the heading of operating losses.

<sup>18</sup>From now on, we will therefore drop the superscript  $i$ .

### 3.5 Financial contracting

Following Holmstrom and Tirole (1998), we now turn to a detailed analysis of the specific contracting problem in our model which - by assumption - is only relevant for the intermediate goods firms operating the advanced technology. Hence, while advanced sector firms face the problem of insuring their production against liquidity shocks, the other firms' respective problems are standard. The sequencing of events underlying an individual advanced firm's within-period<sup>19</sup> contracting problem can be decomposed into three stages; compare Figure 1.

At *stage one*, after aggregate uncertainty with respect to  $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$  is unveiled, each advanced firm, run by an entrepreneur holding an equity position  $E_t$  in the firm, contracts with the financial intermediary to pin down its production plan and refinancing provisions.<sup>20</sup> In particular, the refinancing provisions determine the degree of insurance against idiosyncratic liquidity risk.<sup>21</sup> Given  $s_t$ , a contract between the financial intermediary (outside investor) and the entrepreneur (firm) holding equity  $E_t$  prescribes (i) the scale of production as determined by factor employment  $z_t, l_t^z$ , (ii) a state contingent continuation rule  $\Gamma_t(\xi_t)$ , and (iii) a state contingent transfer  $\tau_t(\xi_t)$  from the firm to the investor. Hence, a generic contract takes the form  $\mathcal{C}_t = \{z_t, l_t^z, \Gamma_t(\xi_t), \tau_t(\xi_t)\}$ . A constraint on the contract is that it is written under limited liability, i.e. in case of project termination factors must be remunerated by the outside investor. At a subsequent interim stage (*stage two*) after the factor employment decisions have been made, the firm is hit by an idiosyncratic liquidity shock  $\xi_t$ . If the shock is met by appropriate refinancing to be provided by the intermediary, the firm can continue; otherwise the firm is liquidated. We assume that the liquidity shock is verifiable, but it is shown in Holmstrom and Tirole (1998) that nothing changes if only the firm observes the shock as long as the firm does not benefit from diverting resources. After the continuation decision, there is scope for moral hazard on the part of the entrepreneur in that she can exert effort to affect the distribution of production outcomes. Specifically, we make the extreme assumption that, conditional on continuation, exerting effort guarantees a gross return of  $P_t^z \mathcal{V}_t f(z_t, l_t^z) = P_t^z \tilde{y}_t^z$  to production activity, while shirking leads to zero output, but generates a private (non-monetary) benefit  $B_t$ . We assume that the private benefit is proportional to firm revenue conditional on survival; in particular, we have:  $B_t = b P_t^z \mathcal{V}_t f(z_t, l_t^z) = b P_t^z \tilde{y}_t^z$  with  $0 < b < 1$ .<sup>22</sup> Finally, at *stage three*, the revenue from production accrues and payoffs are realized according to the rules stipulated in the financial contract. The financial intermediary engages in a continuum of contracts with advanced sector firms; hence, since liquidity risk is idiosyncratic, the intermediary is able to pool the risk inherent in the investments across individual firms' projects. As an implication, we can completely abstract from the effects of idiosyncratic uncertainty on the investor's evaluation of payoffs. Similarly, the entrepreneur who is exposed to her uninsured private equity risk is risk

<sup>19</sup>Although the firm's production plan is conditional on the predetermined entrepreneurial equity position  $E_t$ , the firm problem itself is not dynamic because entrepreneurial asset accumulation proceeds mechanically and there is no intertemporal incentive provision.

<sup>20</sup>We assume that entrepreneurial self-financing is not possible; a sufficient condition for this to be the case is derived below.

<sup>21</sup>It is important to realize that the financial contract is negotiated after fresh cash  $\mathcal{J}_t$  has been injected into the economy. Consequently, the results of monetary policy that we will develop in the sequel do not stem from an implicit nominal rigidity. On the contrary, our concept of corporate liquidity is entirely real; what is affected by nominal fluctuations, however, is the price of such liquidity.

<sup>22</sup>Note, however, that the specific value of  $b > 0$  will not matter as long as the contract to be derived below delivers an interior solution.

neutral and cares only about expected profits as long as she is active.

Hypothetically abstracting from both the entrepreneurial incentive constraint and the cost of obtaining liquidity at the interim stage, it is easy to see that there exists a unique cutoff value of  $\xi$  corresponding to a continuation policy which prescribes project continuation if and only if the liquidity shock is such that  $\xi \leq 1$ . The reason is that the stage one investment is sunk; hence, at the interim stage, it is optimal to refinance up to the full value of what can be generated in terms of revenue at the final stage. However, the need to take into account the incentive constraint and the costs of liquidity provision implies that the constrained-efficient continuation policy will take the form:

$$\Gamma_t(\xi_t) = \begin{cases} 1, & \text{if } \xi_t \leq \hat{\xi}_t \\ 0, & \text{if } \xi_t > \hat{\xi}_t \end{cases}$$

for some cutoff value  $\hat{\xi}_t < 1$ . Hence,  $\Gamma_t(\xi_t)$  is a simple indicator function with  $\Gamma_t(\xi_t) = 1$  in case of continuation and  $\Gamma_t(\xi_t) = 0$  in case of termination.

A constrained-efficient contract  $\mathcal{C}_t = \{z_t, l_t^z, \Gamma_t(\xi_t), \tau_t(\xi_t)\}$  with  $(z_t, l_t^z)$  determining the scale of production, and  $\Gamma_t(\xi_t)$  and  $\tau_t(\xi_t)$  pinning down the state contingent policies for project continuation and transfers per unit of production costs  $C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z)$ , respectively, then solves the following second best program of maximizing the entrepreneur's net return:

$$\max_{\mathcal{C}_t} \int \left\{ \Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z) \right\} dG(\xi_t) - E_t \quad (14a)$$

subject to a participation constraint for the investor that requires him to break even in expectation:

$$\int \left\{ \tau_t(\xi_t) C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z) - \Gamma_t(\xi_t) \xi_t \tilde{R}_t P_t^z \tilde{y}_t^z \right\} dG(\xi_t) \geq C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z) - E_t \quad (14b)$$

and a state-by-state incentive compatibility constraint for the entrepreneur:

$$\Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z) \geq \Gamma_t(\xi_t) b P_t^z \tilde{y}_t^z \quad \forall \xi_t, \quad (14c)$$

where:

$$\tilde{y}_t^z = \mathcal{V}_t(z_t)^{\alpha^z} ((1 + \gamma)^t l_t^z)^{1 - \alpha^z}$$

is firm level output conditional on survival and:

$$C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z) = [1 + \theta(\tilde{R}_t - 1)] W_t^z l_t^z + R_t^z z_t$$

are the associated total costs which accrue when a output level of  $\tilde{y}_t^z$  is targeted in case of survival. Note how the specification of this problem, by means of the participation constraint (14b), incorporates the requirement that the investor who bears the risk of project failure be willing to finance the firm, whereby the outside investor commits both the factor remuneration and the interim resources needed to meet the liquidity shock. The cost of providing liquidity at the interim stage, which has to be obtained in the financial market at the financial rate  $\tilde{R}_t$ ,

will be key in shaping the solution to problem (14).

**Optimal factor input ratio and the cost function:** Obviously, part of the optimal contract must be to use factor inputs in a cost minimizing combination. However, since factor demands are determined via the contract  $\mathcal{C}_t$ , they will not only reflect the firm's profit maximization objective, but also the intermediary's need to break even in expectation. With our Cobb-Douglas specification, the possibility of project failure then requires that factors earn constant shares not of firm revenue, but of the total costs  $C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z)$  associated with a targeted production scale  $\tilde{y}_t^z$ . Hence, the demands for capital and labor are:

$$z_t = \frac{\alpha^z C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z)}{R_t^z} \quad \text{and} \quad l_t^z = \frac{(1 - \alpha^z) C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z)}{[1 + \theta(\tilde{R}_t - 1)]W_t^z} \quad (15)$$

Furthermore, from constant returns to scale and the Cobb-Douglas specification of the technology, we can write:

$$C(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z) = MC_t^z(W_t, R_t^z, \tilde{R}_t) \tilde{y}_t^z = \frac{1}{\mathcal{V}_t} \left( \frac{R_t}{\alpha^z} \right)^{\alpha^z} \left( \frac{[1 + \theta(\tilde{R}_t - 1)]W_t^z}{(1 - \alpha^z)} \right)^{(1 - \alpha^z)} \tilde{y}_t^z,$$

where  $MC_t^z(\cdot)$  are the per unit costs of producing a targeted output level  $\tilde{y}_t^z$ ; since the technology displays constant returns to scale, these per unit costs coincide with marginal costs. Note that, as a consequence, the program to find the optimal contract is linear in the project size  $\tilde{y}_t^z$ .

**First best - the socially optimal contract:** Let us first look at the first best contract where  $b = 0$  such that the entrepreneurial moral hazard problem plays no role (but liquidity is scarce and has an opportunity cost  $\tilde{R}_t$ ). The questions asked here are, what is the maximum overall return on investment, and how does the corresponding socially optimal contract look like? Suppose for the moment a binding participation constraint for the investor; indeed, we will later verify that this is the case in a well-specified problem.<sup>23</sup> Substituting from the binding participation constraint (14b) into the entrepreneur's net return (14a) yields:

$$\Pi_t^F = \left[ \int \Gamma_t(\xi_t) \frac{P_t^z}{MC_t^z(\cdot)} (1 - \xi_t \tilde{R}_t) dG(\xi_t) - 1 \right] MC_t^z(\cdot) \tilde{y}_t^z$$

Let  $\hat{\xi}_t$  denote the cutoff value for the liquidity shock such that the project is continued if and only if  $\xi_t \leq \hat{\xi}_t$ ; using this rule for the indicator function then allows to rewrite the entrepreneur's net return as:

$$\Pi_t^F(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t) MC_t^z(\cdot) \tilde{y}_t^z, \quad (16a)$$

where:

$$\lambda_t(\hat{\xi}_t) \equiv \left[ \int_0^{\hat{\xi}_t} \frac{P_t^z}{MC_t^z(\cdot)} (1 - \xi_t \tilde{R}_t) dG(\xi_t) - 1 \right] \quad (16b)$$

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<sup>23</sup>By well-specified, we mean (i) that there is no self-financing by the firms, and (ii) that the solution to the constrained-optimal contract features a finite investment level.

In definition (16b),  $\lambda_t(\hat{\xi}_t)$  denotes the net social marginal return on one unit invested in an individual advanced sector project, given a cutoff value  $\hat{\xi}_t$ . Since  $\frac{P_t^z}{MC_t^z(\cdot)} > 0$ ,  $\lambda(\hat{\xi}_t)$  is maximized at the socially optimal cutoff value  $\hat{\xi}_t^{FB} = \frac{1}{\tilde{R}_t}$ . Moreover, from (16a), it is clear that the entrepreneur is the residual claimant and receives the full social surplus from the project.

**Second best - entrepreneurial moral hazard:** Now consider the case where  $b > 0$ . First of all note that general equilibrium considerations imply that the marginal net social return under both the first and the second best solution must be positive.<sup>24</sup> Then, given a positive value for  $\lambda_t(\hat{\xi}_t)$ , the entrepreneur will seek to maximize  $\Pi_t^F(\hat{\xi}_t)$  by choosing the maximum investment volume  $MC_t^z(\cdot)\tilde{y}_t^z$  that still guarantees investor participation. But from (14b), this is achieved by maximizing the state contingent per unit transfer  $\tau_t(\xi_t)$  to the investor. Accordingly, the second best contract prescribes to retain the minimum amount of profits in the firm that is still consistent with incentive compatibility. Hence, the entrepreneur's incentive compatibility constraint (14c) is binding at the maximum pledgeable unit return:

$$\tau_t(\xi_t) = \frac{\Gamma_t(\xi_t)(1-b)P_t^z\tilde{y}_t^z}{MC_t^z(\cdot)\tilde{y}_t^z} \quad (17)$$

We can now solve for the largest investment volume  $MC_t^z(\cdot)\tilde{y}_t^z$  that is compatible with both the investor's participation constraint and the entrepreneur's incentive constraint by substituting the maximum pledgeable unit return (17) into the investor's participation constraint (14b) to obtain:

$$\left[ 1 - \int \Gamma(\xi_t) \left( (1-b) - \xi_t \tilde{R}_t \right) \frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t) \right] MC_t^z(\cdot)\tilde{y}_t^z = E_t \quad (18)$$

Here, the expression in squared brackets represents the difference between marginal cost of investment to an outside investor and the expected marginal return to such outside investment. Let  $\hat{\xi}_t^0 \equiv \frac{(1-b)}{\tilde{R}_t}$  denote the cutoff value that maximizes the expected marginal return to outside investors, and note that equation (18) implies that, given some  $E_t > 0$ , the expected (subject to idiosyncratic liquidity shocks) marginal return on outside investment is strictly smaller than one.<sup>25</sup>

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<sup>24</sup>To see this, suppose to the contrary that  $\lambda(\hat{\xi}_t^{FB}) \leq 0$  such that the optimal contract would prescribe  $z_t = l_t^z = 0$ , i.e. zero investment for any level of entrepreneurial equity  $E_t$ . However, this implies  $\tilde{y}_t^z = 0$  which contradicts a general equilibrium with positive consumption and investment, and the price of the advanced intermediate good would adjust such as to guarantee a positive marginal net social return. By the same token, the second best solution must also involve a cutoff rule  $\hat{\xi}_t$  with positive marginal net social return.

<sup>25</sup>Indeed, if this was not the case, investment would be self-financing and there would be no demand for liquidity at all in that the investor's participation constraint would be non-binding. A sufficient condition for ruling out self-financing is:

$$\int_0^{\hat{\xi}_t^0} \left( (1-b) - \xi_t \tilde{R}_t \right) \frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t) < 1$$

Observe that rewriting this condition yields  $\lambda_t(\hat{\xi}_t^0) < b \frac{P_t^z}{MC_t^z(\cdot)} G(\hat{\xi}_t^0)$ ; then, it is apparent that  $\hat{\xi}_t^{FB} = \hat{\xi}_t^0$  if  $b = 0$ , which leads to the conclusion that, in order to rule out self-financing, a positive wedge  $\hat{\xi}_t^{FB} - \hat{\xi}_t^0 > 0$  and therefore  $b > 0$  are essential.

Solving equation (18) for the maximum investment volume conditional on a given cutoff value  $\hat{\xi}_t$ , allows to write the firm's investment capacity as:

$$MC_t^z(\cdot)\tilde{y}_t^z = \mu_t(\hat{\xi}_t)E_t, \quad (19a)$$

where:

$$\mu_t(\hat{\xi}_t) \equiv \frac{1}{1 - \int_0^{\hat{\xi}_t} \left( (1-b) - \xi_t \tilde{R}_t \right) \frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t)} \quad (19b)$$

is an equity multiplier, whose denominator specifies the amount of internal funds that the firm has to contribute per unit of investment in order to compensate the outside investor for the shortfall implied by the expression in squared brackets in (18). Finally, using (16a) and (19a), the entrepreneur's expected net payoff becomes:

$$\Pi_t^F(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t)\mu_t(\hat{\xi}_t)E_t \quad (20)$$

It now remains to determine the second best continuation threshold, to be denoted  $\hat{\xi}_t^*$ . Given an entrepreneurial equity position  $E_t$ , the second best cutoff  $\hat{\xi}_t^*$  maximizes (20). It is clear that  $\hat{\xi}_t^* \in [\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$ : If  $\xi_t < \hat{\xi}_t^0$ , then both parties prefer to continue ex post because both parties can realize gains on the sunk stage one investment; if  $\xi_t > \hat{\xi}_t^{FB}$ , then both parties prefer to abandon the project because the net social marginal return of continuing is negative. Within the interval  $[\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$ , there emerges a trade-off: On the one hand, increasing  $\hat{\xi}_t$  implies that continuation is possible in more contingencies, and thus the marginal net social return  $\lambda_t(\hat{\xi}_t)$  on each unit of initial investment is increased. On the other hand, decreasing  $\hat{\xi}_t$  allows to increase the amount of initial investment  $MC_t^z(\cdot)\tilde{y}_t^z$  by increasing the equity multiplier  $\mu_t(\hat{\xi}_t)$ . After substitution from the definitions (16b) and (19b) into (20), it is straightforward to show that the optimal continuation value  $\hat{\xi}_t^*$  can be found as the solution to the following problem:

$$\min_{\hat{\xi}_t} \frac{\tilde{R}_t \int_0^{\hat{\xi}_t} \xi_t dG(\xi_t) + \frac{MC_t^z(\cdot)}{P_t^z}}{G(\hat{\xi}_t)}, \quad (21)$$

which has the interpretation that the second best cutoff value minimizes the expected unit cost of total expected investment. The first order condition to this problem is:

$$\int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t = \frac{MC_t^z(\cdot)}{P_t^z} \frac{1}{\tilde{R}_t} \quad (22)$$

Finally, using the optimality condition for the cutoff value allows to rewrite the entrepreneur's expected net return in the following compact form:

$$\Pi_t^F(\hat{\xi}_t^*) = \frac{\frac{1}{\tilde{R}_t} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \frac{(1-b)}{\tilde{R}_t}} E_t = \frac{\hat{\xi}_t^{FB} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \hat{\xi}_t^0} E_t \quad (23)$$

Observe how this expression reflects the trade-off underlying the choice of  $\hat{\xi}_t^* \in [\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$ . For future reference, we define the expected net return per unit of entrepreneurial equity  $E_t$  as:

$$\tilde{\Pi}_t^F(\hat{\xi}_t^*) \equiv \frac{\frac{1}{\tilde{R}_t} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \frac{(1-b)}{\tilde{R}_t}}$$

**Implementation and aggregate liquidity demand:** In order to cover liquidity shocks up to the second best cutoff  $\hat{\xi}_t^*$ , it is necessary that outside investors commit funds at the initial contracting stage (*stage one*). The reason is that, by issuing corporate claims at the interim stage (*stage two*), it is not possible to raise enough funds because the entrepreneurial commitment problem limits the maximum return pledgeable to outside investors at  $\hat{\xi}_t^0 < \hat{\xi}_t^*$ . It is then a natural question to ask how the second best policy can actually be implemented at the initial contracting stage; moreover, in view of our modelling hypothesis that an economy's physical investment portfolio is affected by the degree to which firms can insure their activities by means of holding corporate liquidity, there arises the related question of whether there is a second best policy that features firms (rather than the intermediary) holding liquidity. These questions are dealt with in Appendix B.1. Here, suffice it to stress (i) that second best contracting indeed is consistent with liquidity holdings at the firm level and (ii) that under financial intermediation, which efficiently economizes on the use of scarce liquidity by pooling liquidity risk across firms, the aggregate demand for liquidity is:

$$D_t^* = \left[ \int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t \right] P_t^z \tilde{y}_t^z < \bar{D}_t \quad (24)$$

### 3.6 Empirical implications

As an immediate consequence of optimal financial contracting as derived in Section 3.5, we put on record the following empirical implications of optimal financial contracting as governed by equation (22), which will be subject of our later empirical analysis of industry and firm-level panel data.

- $\mathcal{H}1$ : *Ceteris paribus*<sup>26</sup>, an increase in  $\tilde{R}_t$  leads to a lower cutoff  $\hat{\xi}_t^*$ :

$$\frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} = - \frac{\int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t}{\tilde{R}_t G(\hat{\xi}_t^*)} < 0, \quad (25)$$

which follows from total differentiation of condition (22).

Thus, quite intuitively, higher nominal interest rates  $\tilde{R}_t$  lead to smaller hedging against idiosyncratic liquidity shocks because the intermediary's participation constraint gets tighter in line with the increased costs of providing liquidity. In order to examine the effects of other changes in the economic environment on firms' liquidity demand, we establish two auxiliary results. *First*, increased volatility of the liquidity shock distribution  $G(\cdot)$  in the sense of a mean-preserving spread implies a lower cutoff value  $\hat{\xi}_t^*$ ; formally  $\frac{\partial \hat{\xi}_t^*}{\partial \sigma_\xi} < 0$ .<sup>27</sup> The intuition behind this result is that increased risk makes the option to terminate the project more valuable.

<sup>26</sup>The claimed result obtains if, to a first approximation,  $\frac{MC_t^z(\cdot)}{P_t^z}$  remains constant. That is, the results derived in the following are valid from a partial equilibrium perspective; taking into account general equilibrium effects does not change the qualitative (sign) properties of the relevant derivatives. Compare the results from the simulation of the full-blown general equilibrium model reported below.

<sup>27</sup>Variations in the standard deviation  $\sigma_\xi$  need to be restricted to mean-preserving spreads, the result then obtains by partial integration; compare Mas-Colell, Whinston and Green (1995), chapter 6.

The empirical prediction therefore is that firms operating in a more volatile environment are insured to a smaller degree. *Second*, situations where production by means of the advanced technology is more profitable, i.e. situations characterized by lower ratios  $\frac{MC_t^z(\cdot)}{P_t^z}$ , are predicted to feature a lower  $\hat{\xi}_t^*$ ; formally  $\frac{\partial \hat{\xi}_t^*}{\partial (MC_t^z/P_t^z)} > 0$ .<sup>28</sup> The reason for the poorer insurance of more profitable projects is the contracting trade-off underlying the choice of  $\hat{\xi}_t^*$ : While a more generous provision with liquidity has the advantage of withstanding larger shocks, it necessarily implies a lower stage one investment volume. Thus, for highly profitable projects, both contracting parties prefer to cut  $\hat{\xi}_t^*$  in order to expand the project size. Based on these results, we can derive two additional hypotheses relating to the sensitivity of specific firms (or industries) to fluctuations in the nominal interest rate.

- $\mathcal{H}2$ : Increased production risk (in the form of a mean-preserving spread of the distribution  $G(\cdot)$ ) accentuates the negative effect of  $\tilde{R}_t$  on the cutoff  $\hat{\xi}_t^*$ :

$$\frac{\partial}{\partial \sigma_\xi} \left( \frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} \right) = \frac{\partial \hat{\xi}_t^*}{\partial \sigma_\xi} \frac{\partial}{\partial \hat{\xi}_t^*} \left( \frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} \right) < 0, \quad (26)$$

where the inequality follows from the fact that  $\hat{\xi}_t^*$  is decreasing in the volatility of the shock distribution and differentiation of expression (25) with respect to  $\hat{\xi}_t^*$ .

- $\mathcal{H}3$ : Increased profitability accentuates the negative effect of  $\tilde{R}_t$  on the cutoff  $\hat{\xi}_t^*$ :

$$\frac{\partial}{\partial (MC_t^z/P_t^z)} \left( \frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} \right) = \frac{\partial \hat{\xi}_t^*}{\partial (MC_t^z/P_t^z)} \frac{\partial}{\partial \hat{\xi}_t^*} \left( \frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} \right) > 0, \quad (27)$$

where the inequality follows from the fact that  $\hat{\xi}_t^*$  is increasing in the marginal-cost-to-price ratio and differentiation of expression (25) with respect to  $\hat{\xi}_t^*$ .

Starting from the supposition that the economy's productive activity is organized based on a set (here: two) of distinct available technologies, we can infer a measure  $\mathcal{T}_t$  of aggregate productivity. This measure is derived from the concept of an aggregate production function  $F(K_t, L_t) = K_t^\alpha ((1 + \gamma)^t L_t)^{(1-\alpha)}$ , interpreted as an equilibrium relationship between aggregate inputs and outputs, whereby output fluctuations which cannot be associated with changes in factor accumulation or employment record as changes in TFP. With the underlying structure of a one-sector neoclassical growth model,  $\mathcal{T}_t$  would be interpreted as a residual process. Conversely, the argument put forward within the framework of our two-sector model is to acknowledge that  $\mathcal{T}_t$  is not exclusively determined by an exogenous process, but also affected by endogenous shifts in the composition of economic activity. In detail, as shown in Appendix B.2, we derive our aggregate measure of TFP such that changes in  $\mathcal{T}_t$  can be decomposed as follows:

$$\hat{\mathcal{T}}_t = \omega_{yk,t}^y \hat{\mathcal{A}}_t + \omega_{yz,t}^y \left( \hat{\mathcal{V}}_t + \omega_{\hat{\xi}_t^*,t}^G \hat{\xi}_t^* \right) \quad (28)$$

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<sup>28</sup>This follows from total differentiation of condition (22), for given  $\tilde{R}_t$ .

This expression illustrates how changes in  $\mathcal{T}_t$  can be expressed as a weighted sum of changes in the sectoral productivity levels  $\mathcal{A}_t$  and  $\mathcal{V}_t$ . The endogenous weights attached to  $\widehat{\mathcal{A}}_t$  and  $\widehat{\mathcal{V}}_t$  are given by the elasticity terms  $\omega_{yk,t}^y$  and  $\omega_{yz,t}^y$  which underpin the importance of the sectoral composition of production activities; moreover, since the elasticity terms, defined in (9), are formulated in terms of *realized* intermediate output levels, the effect of  $\widehat{\mathcal{V}}_t$  is amended by the term  $\omega_{\hat{\xi}^*,t}^G \widehat{\xi}_t^*$  which reflects how the level of *realized* advanced sector output  $y_t^z$  (as opposed to  $\tilde{y}_t^z$ , the relevant quantity *conditional on survival*) responds to changes in the degree of insurance against liquidity risk provided to production in the advanced sector. Thus, besides the exogenous processes  $\mathcal{A}_t$  and  $\mathcal{V}_t$ , there are two endogenous sources of fluctuations in measured TFP: First, shifts in the sectoral allocation of physical investments  $k_t, z_t$  - an investment composition effect; and second, for a given composition of aggregate investment, changes in the effectiveness of transforming hired factor inputs  $z_t, l_t^z$  into *realized* output  $y_t^z$  - an insurance effect in response to changes in the liquidity premium. Now, building on equations (25) and (28), the model's key implication for aggregate fluctuations is obtained.

- $\mathcal{H}4$ : For given realizations of  $\mathcal{A}_t$  and  $\mathcal{V}_t$ , an increase in  $\tilde{R}_t$  leads to a drop in TFP:

$$\frac{\partial \mathcal{T}_t}{\partial \tilde{R}_t} = \omega_{yz,t}^y \omega_{\hat{\xi}^*}^G \frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} < 0, \quad (29)$$

where the inequality follows from  $\omega_{yz,t}^y, \omega_{\hat{\xi}^*}^G > 0$  and (25).

Finally, differentiation of equation (29) gives rise to a prediction concerning the differential impact of nominal fluctuations across different industries:

- $\mathcal{H}5$ : Higher exposure to the advanced technology, as measured by a higher  $\omega_{yz,t}^y$ , implies a higher responsiveness of TFP to movements in the  $\tilde{R}_t$ :

$$\frac{\partial}{\partial \omega_{yz,t}^y} \left( \frac{\partial \mathcal{T}_t}{\partial \tilde{R}_t} \right) = \omega_{\hat{\xi}^*}^G \frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} < 0, \quad (30)$$

which follows from  $\omega_{\hat{\xi}^*}^G > 0$  and (25).

### 3.7 Government policy

In order to close the model, a specification for government policy is needed. We will consider two regimes of government policy. The first one (*regime 1*) is based on an exogenous process for monetary policy which consists of periodic injections  $\mathcal{J}_t$  of money in the financial market.  $\mathcal{J}_t$  is implicitly defined as  $\mathcal{J}_t = (e^{mg_t} - 1)(M_t + A_t)$ , where  $mg_t$  is the gross rate of money growth. Hence, the aggregate of nominal wealth held by households and entrepreneurs is updated according to:

$$(M_{t+1} + A_{t+1}) = e^{mg_t} (M_t + A_t)$$

The gross rate of money growth  $mg_t$  is assumed to evolve according to an autoregressive mean-reverting process:

$$mg_t = \rho_j mg_{t-1} + (1 - \rho_j) mg^* + \epsilon_{j,t}, \quad \epsilon_j \sim \mathcal{N}(0, \sigma_j^2),$$

where  $mg^*$  is the steady state level of money growth, which together with the economy's exogenous (balanced) growth rate  $\gamma$  determines the rate of inflation prevailing in steady state. In our analysis of the dynamics of the linearized model, we will recur to regime 1 in order to investigate the dynamic effects of a shock to monetary policy.

The other regime (*regime 2*) makes a step towards endogenizing monetary policy by postulating that there is a cyclical motive for monetary policy. Specifically, we assume that, in an effort to foster the efficient allocation of resources, the monetary authority implements a policy which reacts to shocks in the relative productivity of the two sectors:

$$mg_t = \rho_j mg_{t-1} + (1 - \rho_j) \left[ mg^* + \ln \left( \frac{\mathcal{V}_t}{\chi \mathcal{A}_t} \right) \right] + \epsilon_{j,t}, \quad \epsilon_j \sim \mathcal{N}(0, \sigma_j^2),$$

where  $\chi$  is equal to the steady state value of  $\frac{\mathcal{V}_t}{\mathcal{A}_t}$  such that along the balanced growth path, regime 1 and regime 2 are equivalent. The rationale for adopting regime 2 is a liquidity management one: In situations when it is particularly profitable to produce in the advanced sector, monetary policy is expansive such as to facilitate the provision of liquidity for the purpose of insuring liquidity risk. We are interested in the effects of adopting this policy rule in order to investigate the scope for active liquidity management on the part of the government in an environment with rationally forward-looking agents.

### 3.8 Equilibrium

We are now ready to define a competitive equilibrium of the economy.

**Definition 1 (Competitive Equilibrium)** *Given initial conditions  $\{k_0, z_0, A_0, M_0\}$  and realizations for aggregate shocks  $\{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}_{t=0}^\infty$  and idiosyncratic shocks  $\{\xi_t^i\}_{t=0}^\infty$ , a competitive equilibrium is a list of allocations  $\{c_t^H, h_t^{k,H}, h_t^{z,H}, x_t, k_{t+1}, z_{t+1}, Q_t, M_{t+1}\}_{t=0}^\infty$  to households and  $\{c_t^{E,i}, h_t^{k,E}, h_t^{z,E}, E_t^i, A_{t+1}^i\}_{t=0}^\infty \forall i$  to entrepreneurs, of sectoral and economywide aggregates  $\{c_t, l_t^k, l_t^z, L_t, K_{t+1}, y_t^k, y_t^z, y_t\}_{t=0}^\infty$  and of prices  $\{P_t, P_t^z, P_t^k, W_t, W_t^k, W_t^{k,H}, W_t^{k,E}, W_t^z, W_t^{z,H}, W_t^{z,E}, R_t, R_t^k, R_t^z, \bar{R}_t\}_{t=0}^\infty$  such that:*

1. *given prices, the allocation solves the household problem (1) as well as the basic and advanced firm problems (10) and (14);*
2. *entrepreneurs follow their behavioral rules and the financial intermediary breaks even;*
3. *aggregation across agents and sectors as well as among the entrepreneurs obtains, i.e. for a generic variable  $v_t^{E,i}$  belonging to the allocation to entrepreneurs:  $\int_i v_t^{E,i} di = v_t^E$ ;*
4. *the financial market as well as the markets for final goods, intermediate goods and factor inputs clear.*

A set of useful-to-understand aggregate relations characterizing a competitive equilibrium is derived in Appendix B.3.

## 4 Quantitative model analysis

### 4.1 Calibration

The model is calibrated to US time series at quarterly frequency, whereby we mainly exploit the model's implications for its balanced growth path and data on relevant long-run averages. The quarterly time horizon implies a focus on the business cycle dimension of the questions we seek to analyze. To that end, we employ macroeconomic aggregates and amend them by industry level data in order to calibrate the parameters that pin down the sectoral composition of economic activity. A description of the data as well as the details of our calibration exercise are contained in Appendix B.4.

To operationalize the calibration exercise, functional forms need to be specified. As to household preferences, we work with two alternative specifications of the period utility function.<sup>29</sup> The first one follows Greenwood, Hercovitz and Huffman (1998) and assumes:

$$u(c^H, h^H) = \frac{1}{1-\sigma} [c^H - \psi(1+\gamma)^t(h^H)^\nu]^{1-\sigma}, \quad \nu > 1, \psi > 0$$

These preferences, henceforth labelled GHH, have the implication that labor supply is independent of consumption and thus of the real interest rate.<sup>30</sup> In the context of the limited participation structure of our model, the GHH specification is therefore a useful tool to analyze the effects of (monetary) shocks because changes in employment are exclusively induced by changes in labor demand.<sup>31</sup> The second specification introduces sensitivity of labor supply with respect to changes in the real interest rate by considering a Cobb-Douglas utility function in consumption  $c^H$  and leisure  $(1 - h^H)$ :

$$u(c^H, h^H) = \frac{1}{1-\sigma} [(c^H)^\mu (1 - h^H)^{1-\mu}]^{1-\sigma}, \quad 0 < \mu < 1$$

The production functions describing the two available technologies have already been introduced with a Cobb-Douglas specification. Thus, it only remains to specify the adjustment cost function associated with variations in sector-specific capital  $i = k, z$ :

$$\Phi(i_t, i_{t+1}) = \frac{\phi}{2} i_t \left( \frac{i_{t+1} - i_t(1+\gamma)}{i_t} \right)^2,$$

which guarantees that, as the economy grows, the average resources spent in terms of adjustment costs remain constant and that along a balanced growth path the costs are zero. Finally, the exogenous shocks to sectoral productivity are assumed to obey the following autoregressive processes:<sup>32</sup>

$$\begin{aligned} \ln(\mathcal{A}_t) &= \rho_a \ln(\mathcal{A}_{t-1}) + \epsilon_{a,t}, & \epsilon_a &\sim \mathcal{N}(0, \sigma_a^2) \\ \ln(\mathcal{V}_t) &= \rho_v \ln(\mathcal{V}_{t-1}) + (1 - \rho_v) \ln(\chi) + \epsilon_{v,t}, & \epsilon_v &\sim \mathcal{N}(0, \sigma_v^2), \end{aligned}$$

<sup>29</sup>Compare Neumeyer and Perri (2005) for a similar approach.

<sup>30</sup>Note that these preferences are consistent with balanced growth if one assumes that the labor augmenting technological process increases the utility from leisure. Benhabib, Rogerson and Wright (1991) provide an interpretation of the GHH preferences as a reduced form for an economy with home production and technological progress in that sector.

<sup>31</sup>Of course, equilibrium movements in employment will still depend on the elasticity of labor supply because shifts in labor demand correspond to a movement along the labor supply schedule.

<sup>32</sup>In our model simulations below, we allow for cyclical comovement by stipulating  $\rho_{av} = \text{corr}(\epsilon_{a,t}, \epsilon_{v,t}) > 0$ .

where  $\chi$  is a measure of the productivity gap between the advanced sector and the basic sector along the balanced growth path. The set of parameters derived on the basis of these specifications is summarized in Table 1.

Table 1: Calibrated parameter values

|         |          |        |          |            |          |            |             |          |            |        |           |              |
|---------|----------|--------|----------|------------|----------|------------|-------------|----------|------------|--------|-----------|--------------|
| $\beta$ | $\sigma$ | $\mu$  | $\nu$    | $\psi$     | $\gamma$ | $\alpha^k$ | $\alpha^z$  | $\delta$ | $\theta$   | $\phi$ | $\Omega$  | $\chi$       |
| 0.98    | 2        | 0.167  | 2.67     | 4          | 0.0037   | 0.31       | 0.31        | 0.0112   | 0.5        | 8      | 0.95      | 2.97         |
| $\eta$  | $\zeta$  | $\rho$ | $\rho_a$ | $\sigma_a$ | $\rho_v$ | $\sigma_v$ | $\rho_{av}$ | $\rho_j$ | $\sigma_j$ | $b$    | $\mu_\xi$ | $\sigma_\xi$ |
| 0.97    | 0.73     | 1.66   | 0.79     | 0.0046     | 0.66     | 0.0083     | 0.67        | 0.875    | 0.0033     | 0.15   | -0.5      | 0.5          |

**A roadmap:** In order to assess the quantitative role of nominal shocks for aggregate fluctuations and in particular for the endogenous evolution of TFP, we now analyze the statistical properties of the model economy. Before doing so, the following comment is expedient, using the routines proposed by Sims (2001): Although the model is calibrated to US data, it is by no means designed to give an accurate account of the business cycle along all dimensions. The reason is that the model stresses the aspects of allocation and insurance of investment over the cycle and also develops a mechanism by which nominal fluctuations affect these choices, but at the same time lacks some key features which the recent macroeconomic literature has identified as important building blocks of successful monetary business cycle models. Among these features are e.g. nominal rigidities beyond the one implicit in the simple limited participation structure of the present model, firm-specific capital, informational frictions and specifications which allow for variable velocity<sup>33</sup> of money. To keep the model tractable, we nevertheless confine ourselves with a relatively parsimonious specification, which - as far as the monetary transmission mechanism is concerned - gives rise to a twofold effect of monetary expansions: A liquidity effect on impact and an inflationary effect which may take time to materialize; besides, none of the monetary modelling devices mentioned above is incorporated. Thus, the purpose of the following analysis is not to engage in a horserace between the present model and alternative monetary business cycle models (indeed, the latter are superior in their capability to statistically replicate the empirically observed fluctuations), but to examine whether our basic hypothesis that monetary shocks account for a sizeable fraction of fluctuations in TFP is of quantitative relevance. We approach this question starting from a series of numerical experiments. *First*, we simulate the model for our benchmark calibration and confront the generated moments with the empirical US business cycle statistics. *Second*, we consider the same model economy, but for  $\sigma_j = 0$ , i.e. without money shocks; this exercise allows us to decompose the volatility of key macroeconomic aggregates - particularly of TFP - into the fractions that are attributable to money and technology shocks, respectively. *Third*, we examine the model economy's differential performance if the monetary policy regime switches from an acyclical process to a systematic liquidity management one. *Finally*, we are interested in the steady state effects

<sup>33</sup>In contrast, the rigid formulation of the present model's CIA constraint forces velocity to remain constant at unity.

of increased nominal distortions, an issue that we approach by comparing the equilibrium allocations of alternative economies which are indexed by different rates of inflation along their balanced growth path.

**Empirical regularities of the US business cycle:** As hinted above, the empirical characteristics of the US business cycle are a useful benchmark to compare our model-generated moments with. The theoretical model is concerned with the endogeneity of aggregate productivity with respect to nominal fluctuations, whereby the transmission mechanism we put forward discriminates between unanticipated and anticipated effects. Acknowledging that also fluctuations at lower-than-business cycle frequencies may play an important role in explaining variations in TFP which are tied to the composition of aggregate investment, in the following we focus on statistics based on quarterly data. Table 2 documents empirical standard deviations as well as cross-correlations of several macroeconomic aggregates with real GDP, inflation and our relevant measure for nominal interest rates, the yield on corporate bonds (Rcorp).<sup>34</sup>

## 4.2 Model-generated moments

**Benchmark calibration:** Our reference economy is the model with standard CRRA preferences of the Cobb-Douglas type, a steady state rate of inflation of 1.31% per quarter and a remaining parametrization as summarized in Table 1. The linearized model is solved and simulated; Table 3 reports standard deviations and cross-correlations with aggregate output and nominal interest rates.<sup>35</sup> A comparison with the relevant figures in Table 2 reveals that the model-generated standard deviations are consistent with the empirical pattern as far as relative magnitudes are concerned, but that the implied volatilities of output and hours worked fall short of their empirical counterparts. The same is true also for the contemporaneous correlations of hours and aggregate investment with aggregate output which display less procyclicality than observed in the data, while the countercyclical nature of money growth is overpredicted. On the other hand, the correlations we are interested in, the ones of nominal interest rates ( $-0.17$ ) and TFP ( $0.58$ ), are accurately replicated. Turning to the comovement with nominal interest rates, the key statistics for our purpose are (i) the negative contemporaneous correlation of TFP which the model predicts at  $-0.38$  versus  $-0.44$  in the data<sup>36</sup> and (ii) inflation's role as a leading indicator. Moreover, past money growth is found to be associated with higher nominal interest rates, whereas the contemporaneous correlation is negative at  $-0.08$  due to the liquidity effect of monetary expansions. Taken together, these facts suggest a systematic

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<sup>34</sup>We prefer the yield on corporate bonds (Moody's Seasoned Aaa Corporate Bond Yield) over other nominal interest rate measures because it is the closest proxy for firms' cost of external finance.

<sup>35</sup>We do not report cross-correlations with inflation because the model's rigid CIA constraint by construction pins down velocity at unity and thus generates a negative correlation between inflation and most indicators of aggregate economic activity (output, hours, investment) which contradicts the procyclical nature of inflation in the data. We mention, however, that the benchmark model features a pronounced and persistent positive effect of money growth on inflation together with an autocorrelation pattern of inflation which fits the data very well; moreover, the model generates a negative correlation of inflation and TFP of  $-0.17$  (versus  $-0.35$  in the data) and inflation is an inverted leading indicator for TFP.

<sup>36</sup>The corresponding figure for the own rate on M2 rather than the yield on corporate bonds is  $-0.29$ ; the relative magnitude of these reflects the dual role of  $\tilde{R}$  in our model as an intertemporal price for households' saving decisions and an intratemporal factor price for firms' production decisions.

effect of monetary policy on TFP, which is transmitted via fluctuations in the nominal interest rate and the associated changes in the composition of aggregate investment.

**Variance decomposition and key correlations:** To further assess the relevance of this mechanism, we resimulate the model, employing the same parametrization, but shutting down monetary shocks by setting  $\sigma_j = 0$ . This exercise facilitates a variance decomposition and is also informative with respect to the cyclical effects of monetary policy. The relevant statistics are reported in the top and middle (first three columns) panels of Table 4. It turns out that the contemporaneous correlation  $\rho(\tilde{R}, y)$  of nominal interest rates with aggregate output switches sign and becomes positive; the opposite is true for the correlation  $\rho(\hat{\xi}^*, y)$  of the optimal cut-off value with aggregate output which becomes negative. Since  $\hat{\xi}^*$  is an inverse measure for the risk associated with the advanced technology, the model's implication (for  $\sigma_j > 0$ ) is that idiosyncratic investment risk evolves in a countercyclical fashion. The sign switch of  $\rho(\hat{\xi}^*, y)$  for the economy without monetary shocks, in turn, suggests that monetary policy may be key in generating this comovement; indeed, in the absence of monetary shocks idiosyncratic risk is found to be procyclical, reflecting the effect of increased corporate demand for short-term credit which drives up the opportunity costs of holding corporate liquidity. The same effect is also responsible for the changed correlation  $\rho(\tilde{R}, \mathcal{T})$  of TFP and nominal interest rates which becomes strongly positive 0.70, whereas it was negative in the economy with money shocks. The obvious reason is that in the benchmark economy surprise expansions generate additional liquidity which facilitate a better insurance of advanced sector production. A further comparison of the correlations induced by the alternative models indicates that the economy with  $\sigma_j = 0$  features a more pronounced cyclicity of both nominal interest rates and TFP compared to the benchmark economy. Finally, comparing the volatility of macroeconomic aggregates in the respective economies with and without money shocks, we conclude that variations in money growth account for a substantial fraction in the volatility of macroeconomic aggregates; in particular, 9.34% of the fluctuations in aggregate productivity can be attributed to monetary shocks.

**Active liquidity management:** Above analysis of model-generated moments has been based on an exogenous process for monetary policy as postulated in *regime 1*. Given the result established in this context that such an exogenous monetary policy is non-neutral with respect to aggregate productivity, it is natural to ask the following question: Can a cyclically responsive policy which provides additional liquidity when production via the advanced technology is particularly valuable successfully stabilize the economy? We seek to examine this question by analyzing the cyclical behavior of the model economy if it is governed by a liquidity management policy as parametrized in *regime 2*.<sup>37</sup> Our findings indicate that there are hazards attached to such an active liquidity management policy in that the volatility of all relevant macroeconomic aggregates is increased rather than curbed. The statistics in the middle panel of Table 4 (columns four to six) indicate that this conclusion holds irrespective of whether the benchmark economy or the alternative economy without monetary shocks are considered. This increased volatility is most straightforwardly understood as resulting from the following mechanism which propagates any shock to  $\frac{v_t}{\chi \mathcal{A}_t}$ , say a positive one. According to

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<sup>37</sup>Note that, since the considered policy rules differ only in their cyclical components and since the linearized solution displays certainty equivalence, the (deterministic) balanced growth paths under both regimes are identical.

the rule underlying *regime 2*, monetary policy reacts by a money injection. On impact, this expansion generates a liquidity effect which indeed facilitates better insurance of production via the advanced technology. However, due to the autocorrelation in the sector-specific technology shocks (and also in money growth rates), rational expectations dictate an increase in the following periods' nominal interest rates. This, in turn, implies that subsequent production via the advanced technology is insured to a smaller degree; hence, realized volatility is scaled up. These adverse effects of a liquidity management policy are evidenced not only by increased volatility measures, but also by the increased correlation (absolute value) of nominal interest rates, the key transmission variable, with aggregate output and productivity as well as with the optimal cutoff  $\hat{\xi}^*$ . Most strikingly, the potential drawbacks of an active liquidity management policy are evidenced for the relevant economies without monetary shocks where the systematic responsiveness of monetary policy to changes in  $\frac{y_t}{\chi A_t}$  scales up the negative correlation  $\rho(\tilde{R}, \hat{\xi}^*)$  between nominal interest rates and the optimal cutoff from  $-0.71$  to  $-0.98$ .

**Steady states:** At a more fundamental level, distortions via increased rates of inflation and nominal interest rates affect the economy's real allocation also along a balanced growth path. Some important indicators for the induced distortions are summarized in the bottom panel of Table 4, which compares steady state allocations across economies that are indexed by different rates of inflation. Moving from left to right, it can be seen that increased rates of inflation one-to-one feed into higher nominal interest rates and thus into a higher liquidity premium for insuring advanced sector production. This changes the allocation in that (i) the composition of aggregate investment as measured by the ratio  $\frac{z}{k}$  is shifted towards the basic technology, and (ii) the amount of corporate liquidity used to hedge advanced sector production decreases. The latter holds true both for the absolute amount  $d = \frac{D}{P}$  of corporate liquidity and two relevant measures of liquidity in relation to aggregate output ( $\frac{d}{y}$ ) or the overall demand for short-term credit ( $\frac{d}{d+\theta wL}$ ). The implication is that the survival probability  $G(\cdot)$  of advanced projects successively decreases, which further aggravates the effect of the distorted composition of aggregate investment as evidenced by the ratio of realized sectoral outputs  $\frac{y^z}{y^k}$  which declines by more than the relative allocation of physical capital. In line with the prediction of  $\mathcal{H}4$ , the relocation of resources induces a fall in aggregate productivity  $\mathcal{T}$ ; as hinted above, this drop in TFP is the consequence of two things: (i) the shift in the composition of aggregate investment towards the basic technology, and (ii) the decreased insurance against liquidity risk in the advanced sector. Indeed, moving from an economy which is governed by a Friedman rule (column one) to an economy characterized by a money growth rate of 10% (column five) leads to a drop in TFP of 5.1%; similarly, moving from a non-inflationary steady state (column two) to the latter economy goes along with a drop in TFP of 4.2%. Finally, we mention that also some cyclical aspects of the different alternative economies change as is evidenced by the correlation pattern of nominal interest rates. Specifically, while the negative correlation between nominal interest rates on the one hand and aggregate output and the optimal cutoff  $\hat{\xi}^*$  on the other hand remains roughly constant, the adverse effects of interest rate shocks on TFP become more pronounced the higher the level of steady state inflation.

The results established on the basis of above experiments suggest that fluctuations in the nominal interest rate can indeed have a quantitatively important effect on the cyclical behavior

of macroeconomic aggregates and in particular on TFP.<sup>38</sup> Relatedly, as far as our main hypothesis of a negative causal effect of inflation and nominal interest rates on TFP is concerned, it is clear that not only cyclical fluctuations, but also level effects do play an important role. In any case, the analysis of model-generated moments does not yet identify our postulated transmission mechanism in the data. For that reason, in the next section, we empirically investigate whether our specific predictions regarding aggregate as well as disaggregate data are of quantitative relevance.

## 5 Empirical analysis

In this section, we investigate empirically whether the qualitative predictions of our model are confirmed by US time series data at business cycle frequency. In a *first step*, we exploit both quarterly and yearly data on TFP-growth, inflation and nominal interest rates as well as a set of control variables (including the degree of financial development) to establish a negative correlation between TFP-growth and inflation. We apply an instrumental variable approach which provides insights into the underlying causal relation. Although our formal model replicates the relevant short-run macroeconomic dynamics of the US business cycle, we cannot be sure whether the empirical correlations are indeed generated by inflation-driven fluctuations in corporate liquidity holdings and compositional investment decisions at the firm level. The point is that the analysis of macroeconomic data is of limited informational value due to the lack of appropriate identifying measures for these microeconomic variables. Therefore, in a *second step*, we employ disaggregate data to confirm the specific microeconomic mechanism underlying our model. First, we use industry-level data to examine whether TFP-growth responds more sensitively to nominal fluctuations (i) in more volatile sectors and (ii) in sectors that are characterized by a relatively high historical TFP-growth. According to our model, we would expect that firms in such more productive sectors are relatively more dependent on nominal asset holdings to insure against liquidity shocks. Second, we apply firm-level data to approve that investments in superior technologies, proxied by firm-level R&D expenses, (i) decline in the level of inflation (or nominal interest rates, respectively) and (ii) are positively related to corporate liquidity holdings as measured by cash and marketable securities. In fact, the negative impact of inflation on corporate R&D investments disappears if we control for fluctuations in corporate holdings of nominal short-run securities.

### 5.1 Aggregate level

**Data and methodology:** We apply data both at quarterly and at yearly frequency since it is not obvious *ex ante* whether the monetary transmission mechanism postulated in our model fully materializes within a quarter.<sup>39</sup> We employ the growth rate of TFP as the dependent

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<sup>38</sup>In order to pinpoint the mechanisms which are responsible for generating our specific results, we have also analyzed the effects of specific parameter changes by means of a sensitivity analysis. The considered variations include perturbations of the difficult-to-calibrate parameters  $\theta$ ,  $\mu_\xi$  and  $\sigma_\xi$  and the consideration of different preference specifications; results are available upon request.

<sup>39</sup>Our approach is based on firm-level adjustments of liquidity holdings and investment portfolio decisions in response to changes in the nominal interest rate; particularly for their physical investments, firms might respond only to more persistent fluctuations in inflation or interest rates.

variable.<sup>40</sup> TFP is constructed as the residual from the aggregate production function implied by our two-sector model - a detailed description of our TFP accounting as well as of the data and the calibration exercise are contained in Appendices B.2 and B.4. Inflation is derived from the first difference of the real consumer price index.<sup>41</sup> In addition, we include real GDP (*rgdp*), the government (*gov - share*) and private (*inv - share*) investment shares relative to GDP and the amount of private credit (*credit*) and financial deposits (*fin*) as institutional and financial control variables.<sup>42</sup> The former data come from the Bureau of Economic Analysis (BEA), while the financial control variables are obtained from Beck and Levine (2000) and are only available at yearly frequencies. As mentioned above, we apply an instrumental variable approach to estimate a causal effect of inflation on TFP-growth, whereby the variance-covariance matrix is derived via the more efficient general method of moments (GMM) procedure. We always include a lagged dependent variable and incorporate heteroscedasticity-robust standard errors in all estimations. Due to the lack of appropriate external instruments, we employ the first two lags of the endogenous variables as internal instruments.<sup>43</sup> We test for the validity of the instruments using the Hansen-test of overidentifying restrictions. Specifically, lagged values are valid instruments in the absence of serial correlation in the error term. The Hansen-test statistic indicates a well-specified econometric model in all reported estimations. Thus, we estimate the following model with GMM:

$$y_t = \alpha y_{t-1} + \beta Z_t + v_t, \quad |\alpha| < 1, \quad t = 2, 3, \dots, T, \quad (32)$$

where  $y_t$  is the dependent variable,  $Z_t$  the matrix of instrumental variables with  $Z_t = [X_{1,t-1}, X_{1,t-2}]$  and  $X_{1,t}$  a vector of the endogenous explanatory variables;  $v_t$  is the error term and  $\alpha$  and  $\beta$  are parameters to be estimated.

**Results:** Table 6 reports the results for US quarterly data. The first column displays the contemporaneous correlation between inflation and TFP-growth controlling for the dynamics of real GDP, the government share and the financial proxies. We observe a lower TFP-growth in quarters that are characterized by relatively high inflation. This correlation is not due to fluctuations in real GDP, an improvement in the degree of financial development or variations in the government share. Moreover, we apply the alternative Durbin-Watson test to reject first- and second-order serial correlation in the error terms. Since we imposed heteroscedasticity-robust standard errors, we can infer that the model is well-specified. At this stage, the results already suggest that the negative correlation between TFP-growth and inflation cannot be explained by conventional monetary business cycle models. The reason is that the former relationship is found to be independent of fluctuations in real GDP, whereas the class of models mentioned above implies that the effect of productivity shocks on inflation is transmitted via movements in real GDP.

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<sup>40</sup>We use the first difference of TFP instead of the level since the time series properties of the latter are close to a unit root process.

<sup>41</sup>The base year is 1995. We also employ the GDP deflator; however, we exclusively report the estimates based on consumer prices since the results are very similar in both cases.

<sup>42</sup>The inclusion of the amount of liquid liabilities or the stock market trading volume relative to GDP as alternative proxies for the degree of financial development does not change our qualitative results reported below.

<sup>43</sup>Throughout, we consider all included variables as potentially endogenous so that all variables are instrumented.

The second column of Table 6 shows the corresponding results for an instrumental variable approach, where we specified the first two lags of the endogenous variables as internal instruments. The Hansen-test statistic indicates that the estimated parameters fit the over-identifying restrictions well. Specifically, it indicates the absence of serial correlation and hence confirms the validity of the internal instruments. The result corroborates the hypothesis that an increase in inflation in a given quarter leads to a decrease in TFP-growth. The coefficient is significant at a 1% significance level.<sup>44</sup> Moreover, an improvement in the degree of financial development augments TFP-growth, while contemporaneous fluctuations in real GDP and the government share are negatively related to productivity growth in our sample. In column three, our benchmark specification, we account for a linear time-trend so that the dependent variable reflects deviations of TFP-growth from a linear trend. Indeed, TFP-growth exhibits a positive significant time trend in our sample. The inclusion of the trend reinforces the negative impact of inflation on TFP-growth.<sup>45</sup>

In column four, we add the private investment share to our basic specification. The rationale behind this is that standard theories of the business cycle and growth effects of inflation are based on the adverse impact on aggregate investment of the implicit tax or the increase in aggregate uncertainty associated with higher rates of inflation.<sup>46</sup> If inflation reduces TFP-growth because it reduces the aggregate amount of private investment, we should expect that the coefficient of inflation becomes insignificant once we add the private investment share to our basic specification. Yet, the negative coefficient of inflation is still significant on a 5% level after controlling for fluctuations in aggregate investment. We infer that the transmission channel of inflation works at least partly independent from private factor accumulation. This result underpins our hypothesis that inflation affects the (qualitative) composition of private investment projects.<sup>47</sup>

Columns five and six of Table 6 examine the robustness of our findings with respect to sample variations. We split the sample in 1975 because of the productivity slowdown recorded since then. In fact, the observed linear time trend is twice as high before the 1975 breakpoint compared with its value afterwards. The negative impact of inflation is very pronounced in the first subsample, but below the full sample average and insignificant in the second subsample. Thus, we are not able to identify a distorting effect of inflation on TFP-growth based on quarterly data in the second sub-sample. In the last two columns of Table 6, we employed the nominal interest rate, measured by the yield on corporate bonds, as an alternative measure of nominal fluctuations. Column seven shows that an increase in the nominal interest rate reduces TFP-growth. The coefficient is significant on a 5% level. Yet, based on quarterly data, the distorting effect is insignificant at conventional levels if we add the private investment share.

Table 7 displays the results based on yearly data. For a yearly frequency, the negative impact of nominal fluctuations, both in terms of the rate of inflation and the yield on corporate bonds,

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<sup>44</sup>The coefficient of inflation resulting from the instrumental variable approach is more negative than the OLS coefficient indicating that the contemporaneous feedback effect from TFP-growth to inflation is, if anything, positive.

<sup>45</sup>We note that the qualitative results remain unchanged if we apply a Hodrick-Prescott filter to detrended the data before we estimate the reduced form relations. This is also true if we start to filter the data in 1975, after a shift in productivity growth realized. The results are available from the authors upon request.

<sup>46</sup>See Cooley and Hansen (1989), Chari, Jones and Manuelli (1995), Jones and Manuelli (1990), Ramey and Ramey (1995) or Stockman (1981) for a discussion of such theories.

<sup>47</sup>This is in line with earlier findings reported in Ramey and Ramey (1995) and Aghion et al. (2005).

on TFP-growth is significant at a 1% level in most estimations. Our baseline specifications suggest that a 1% increase in the rate of inflation reduces TFP-growth by roughly 0.4%. Hence, the distorting effect is not only statistically but also economically significant.<sup>48</sup> The quantitative impact of inflation does not decline if we control for fluctuations in private investment. Similarly, and in contrast to the results for quarterly data, the negative impact of the nominal interest rate is even more pronounced if we control for fluctuations in private investment.<sup>49</sup>

Summing up, we detect a robust negative empirical relation between inflation and TFP-growth in the US at quarterly as well as yearly frequencies; this finding also extends to the relationship between nominal interest rates and TFP-growth, thus confirming our prediction  $\mathcal{H}4$  developed above. The results based on the yearly frequency are more robust with respect to sample variations. Yet, in both cases, the instrumental variable approach suggests that causation is running from inflation or alternatively the nominal interest rate to TFP-growth. Moreover, we are able to show that the negative relation between inflation and TFP-growth is independent from fluctuations in real GDP or private investment. Both empirical observations, (i) the direction of causality and (ii) the irrelevance of movements in real GDP or private investment are consistent with our theoretical predictions, but challenge the presumption of conventional monetary business cycle theories which take aggregate productivity as an exogenous process and stipulate causality running from TFP to inflation. These findings support our theoretical transmission mechanism which is based on the quality composition of private investment portfolios and the importance of corporate liquidity holdings to hedge superior investment projects. In the following, we employ disaggregate US data to further investigate the empirical relevance of these firm-level relations.

## 5.2 Sectoral level

**Data and methodology:** As an implication of  $\mathcal{H}2$ , we are led to hypothesize that the response in terms of the cutoff  $\hat{\xi}^*$  to movements in the nominal interest rate is stronger for firms operating in more volatile industries. A positive correlation between the rate of inflation and nominal interest rates and the fact that a lower  $\hat{\xi}^*$  ceteris paribus leads to lower TFP-growth (compare equation (28)) then together imply that the relation between TFP-growth and inflation is expected to be stronger in more volatile sectors. In addition, following  $\mathcal{H}3$ , we suppose that firms operating in more productive (in terms of historically realized TFP-growth) sectors have access to superior investment opportunities and hence are expected to react more sensitively to nominal fluctuations.<sup>50</sup> We apply 3-digit industry-level data for the US to investigate these

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<sup>48</sup>Note also that the magnitude of this empirical inflation effect of TFP-growth is consistent with the findings from above numerical experiment which compares TFP levels across economies indexed by different steady state rates of inflation; compare the bottom panel of Table 4.

<sup>49</sup>Also in contrast to our previous findings is the result that the negative effect of inflation on TFP-growth is quantitatively similar to the full sample average and statistically significant at a 5% level in both subsamples (columns five and six) if we split the sample in 1975. Thus, we are now able to identify a distorting effect of inflation on TFP-growth also in the second subsample. The results are very similar if we split the sample in 1982. After 1982 variations in inflation rates were relatively modest. Moreover, note that we do not include a linear time trend since it is statistically insignificant in both subsamples.

<sup>50</sup>Note that we refer to changes in investment portfolios within sectors rather than across sectors. Hence, if insurance against idiosyncratic risk becomes more expensive, physical investment is shifted to alternative more secure projects within the same sector. A shift of investment projects across sectors appears to be negligible

hypotheses. The productivity of US industrial sectors is measured by the growth rate of value added from the UNIDO (2002) industrial statistics database. The yearly data are available for 28 industries from 1963-2000.<sup>51</sup> The classification of 3-digit US industries with respect to average volatility (standard deviation) and average growth of productivity in our sample are reported in Table 5. Overall, these rankings comply with the expected outcomes in that more volatile industries tend to have experienced a higher productivity growth.<sup>52</sup> Therefore, identifying (i) volatile and (ii) strongly growing sectors with industries that are highly exposed to the advanced technology (in the sense of a high  $\omega_{yz}^y$ ), we operationalize our empirical analysis by means of  $\mathcal{H}5$ : We divide the sample according to the median, the first and the fourth quartile of both measures. According to our theoretical model, the differential impact of inflation on TFP-growth across the relevant subsamples should result from the different sensitivity of corporate liquidity holdings in response to nominal fluctuations and is expected to be more pronounced in the 14 (7) industries whose volatility/average productivity growth is above the median (in the first quartile).

Apart from the first lag of growth in value added and inflation, we employ the government investment share, exports and imports relative to GDP (*trade*), the terms of trade (*tot*) and the amount of overall credit and financial deposits as control variables. The data on inflation, trade and terms of trade come from the World Development Indicators (WDI), the financial proxies from Beck and Levine (1999) and the government share from Heston, Summers and Aten (2002). In addition, we control for industry fixed effects. Since we apply a dynamic (industry-) panel data model, including a lagged dependent variable, we employ the Arellano and Bond (1991) estimator.<sup>53</sup> The estimation procedure is based on the general method of moments (GMM) and is constructed to yield consistent estimates in dynamic panels; the estimator is often referred to as the difference GMM estimator. Again, the coefficient of inflation can be interpreted as a causal effect on productivity growth since the estimation procedure relies on internal instruments of the endogenous variables. The GMM difference estimator facilitates a test for the validity of the instruments. The key insight here is that the second (or higher order) lag of an endogenous variable is a valid instrument in the absence of second order autocorrelation.<sup>54</sup> We are able to reject second-order autocorrelation in all reported estimation specifications.<sup>55</sup> Thus, we estimate the following model following Arellano and Bond (1991):

$$\Delta y_{i,t} = \beta Z_{i,t} + \delta \Delta X_{2,i,t} + v_{i,t}, \quad i = 1, 2, \dots, N, \quad t = 3, 4, \dots, T, \quad (33)$$

where  $\Delta$  refers to the first difference,  $y_{i,t}$  is the dependent variable,  $Z_{i,t}$  the matrix of instrumental variables consisting of  $t - 2, \dots, 1$  lags of the levels of the lagged dependent and the vector

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since only large diversified firms may have the opportunity to adjust their investments across different industries.

<sup>51</sup>Note that we have to employ yearly frequencies since, as far as we know, quarterly data on value added at industry level are not available. The UNIDO data are identical to the OECD-STAN (2003) data for the US.

<sup>52</sup>Among the ten most volatile sectors, we find industries such as professional & scientific equipment, petroleum refineries, plastic products, industrial chemicals, iron and steel or non-ferrous metals. In contrast, the four least volatile sectors are food products, other chemicals, beverages and printing and publishing.

<sup>53</sup>Similarly, Aghion et al. (2005) apply a (country-) panel estimation based on yearly data to test for business cycle effects of volatility.

<sup>54</sup>More specifically, the second lag must not be correlated with the contemporaneous error term of the model in first differences.

<sup>55</sup>Note that the Sargan test of overidentifying restrictions is not applicable since we incorporate heteroscedasticity-robust standard errors.

$X_{1,i,t}$  of endogenous explanatory variables, while  $X_{2,i,t}$  is a vector of exogenous explanatory variables,  $N$  the number of cross-sections,  $T$  the number of time-periods,  $v_t$  the error term and  $\beta$  and  $\delta$  parameters to be estimated.<sup>56</sup>

**Results:** In all estimations, we reject the presence of second-order serial correlation in the error term which confirms the validity of the internal instruments following Arellano and Bond (1991). The first four columns of Table 8 analyze whether the sensitivity of TFP-growth with respect to inflation is higher in more volatile sectors. The first two columns summarize the results for sectors that feature an average volatility above and below the median, respectively. A yearly increase in inflation by 1% leads to a reduction in TFP-growth by -1.61% in high-volatility sectors, while the effect amounts to -1.18% in low-volatility sectors. The coefficients are significant on a 1% level in both groups. Hence, consistent with  $\mathcal{H}2$ , the distortionary impact of inflation is 27% higher in more volatile sectors. The results are reinforced if we consider the first and fourth quartile. If we exclusively consider the seven most volatile sectors in our sample, the relevant coefficient indicates that a 1% increase in inflation reduces TFP-growth by 2.29% (significance level of 1%) in the corresponding year. In contrast, the effect amounts to -0.56% only and is borderline significant (10% level) if we consider the seven least volatile industries. Columns five to six of Table 8 classify the impact of inflation on productivity growth according to the median of the observed average productivity growth of a given industrial sector in the sample. The coefficient of inflation is -1.7 in above-median industries relative to -1.08 in below-median industries. Thus, in line with the predictions of  $\mathcal{H}3$ , the adverse effect is 37% higher in the historically more productive sectors. However, the results are less clear-cut if we consider the seven most and least productive sectors since the negative effects of inflation, though still significant, are almost equal in both groups.

Overall, the results emerging from the analysis of industry-level corroborate our theoretical predictions that the negative effect of inflation on TFP-growth varies systematically with the productivity ( $\mathcal{H}3$ ) and the riskiness as measured by the sectoral volatility of value added growth ( $\mathcal{H}2$ ) of investment projects across sectors. In particular, we interpret these findings as supportive for our theoretical model's distinction between the basic technology, which is normalized to be free of liquidity risk, and the advanced technology, where there is a superior growth potential, but where idiosyncratic liquidity shocks give rise to a corporate demand for (partial) insurance against such risk. In the next subsection, we will revisit the specific implications arising from this setup on the basis of firm-level data.

### 5.3 Firm level

**Data and methodology:** Microeconomic data on firm-level behavior allow for the most straightforward test of the specific transmission mechanism proposed by our model. Specifically, our model predicts that firms react to nominal fluctuations by reducing their liquidity holdings used to hedge advanced investment projects and by shifting their investment portfolios

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<sup>56</sup>The instrumental variable matrix is of the following form:

$$Z = \begin{bmatrix} y_{i,1} & 0 & 0 & \dots & 0 & \dots & 0 & x_{1,i,1} & 0 & \dots \\ 0 & y_{i,1} & y_{i,2} & \dots & 0 & \dots & 0 & 0 & x_{1,i,1} & \dots \\ \vdots & \cdot & \cdot & \dots & \cdot & \dots & \cdot & \vdots & \cdot & \vdots \\ 0 & 0 & 0 & \dots & y_{i,1} & \dots & y_{i,T-2} & 0 & 0 & \dots \end{bmatrix}$$

towards more secure, but also less productive projects. The rationale underlying this behavior is that increased nominal interest rates mean that liquidity can be obtained only at a higher premium. Thus, we expect that increased corporate liquidity holdings augment the investment in advanced technology projects, while increased nominal interest rates, most prominently as a consequence of higher (expected) rates of inflation, reduce corporate liquidity holdings and trigger an investment composition effect. In order to test these hypotheses, we match the relevant variables employed in section 5.1 with US firm-level data at quarterly as well as yearly frequency from the Compustat database. The latter data relate to the balance sheets of US non-financial firms and cover the effective time periods 1989:1-2000:4 and 1970-2000, respectively. In detail, we include the following firm level data: R&D expenses, the amount of cash and marketable securities (*corp.liquidity*) and the amount of total assets (*assets*).<sup>57</sup> Here, R&D is used as a proxy for investment in superior technologies.<sup>58</sup> The *assets* variable, in turn, reflects overall corporate liquidity holdings and also controls for firm size. All three firm-level variables are measured in millions of dollars. As hinted above, we use the US CPI-based rate of inflation and the yield on corporate bonds to investigate the effect of these macroeconomic variables on firm-level liquidity and investment portfolios.<sup>59</sup> In addition, where available, we exploit information on individual firms' S&P credit rating (*spdrc*)<sup>60</sup> as an additional control variable to isolate the effect of firm-specific credit conditions relative to the aggregate measure for the lending rate faced by non-financial firms.

In this context, we again point out the empirical evidence provided by Opler et al. (1999) based on yearly US firm-level data for 1970-1993. The authors proxy a firm's investment opportunities by its market-to-book value and/or its expenses for R&D, respectively; the risk associated with a firm's cash flow is measured by the standard deviation of its cash flows. The study finds that the value of liquid assets (cash and marketable securities) relative to total net assets averages at 17% for US non-financial firms. Furthermore, they show that firms with higher growth opportunities and riskier cash flows hold on average more liquid assets. We see these empirical findings as strongly supportive of the relevance of corporate liquidity holdings for the purpose of insuring superior, but risky production activities. Against this background, we extend the analysis in Opler et al. (1999) by investigating the impact of inflation and nominal interest rates on corporate cash holdings and firm-level R&D expenses.

We have a balanced panel of over 150000 observations at quarterly frequency and 97000 at yearly frequency.<sup>61</sup> We employ the Arellano and Bond (1991) GMM difference (*GMM - dif*) as well as the Blundell and Bond (1998) GMM system estimator (*GMM - sys*). In contrast to the former, the latter applies additional moment restrictions on the original model in levels, whereby lagged differences are used as additional instrument for the endogenous and predeter-

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<sup>57</sup>The qualitative results are robust to the inclusion of additional firm-level control variables such as operating income before taxes and interest payments, the amount of long-run outstanding debt or interest payments.

<sup>58</sup>If we interpret investments in superior technologies as investments in new technologies, while investments in less productive projects reflect production with conventional technologies, R&D expenses are the most appropriate candidate for an approximation of advanced investments projects.

<sup>59</sup>We stress that our results do not suffer from an aggregation bias and hence are not subject to the caveat raised by Moulton (1990), since we cluster errors at the firm-level to avoid within-group correlation.

<sup>60</sup>The variable is an index number, ranging from 1 to 30 in our sample, whereby a higher value corresponds to a poorer credit rating.

<sup>61</sup>Unfortunately, the S&P index for credit rating is only available for roughly 12000 time observations.

mined variables in levels.<sup>62</sup> Blundell and Bond (1998) show that this procedure is more efficient if explanatory variables are persistent.<sup>63</sup> However, the estimator requires mean stationarity. In all estimations, we employ heteroscedasticity-robust standards errors and cluster errors at the firm level. Finally, note that the mix of macro- and microeconomic data allows for an inspection of causality. More specifically, the coefficient of inflation reflects the causal impact on an individual firm’s (marginal) R&D expenses since the latter have no feedback effect on the aggregate level of inflation.

**Results:** In all estimations, we reject the presence of second-order autocorrelation. Furthermore, the Hansen-test of overidentifying restrictions never rejects the validity of the instruments. Hence, all estimation specifications appear to be well-specified.<sup>64</sup> Table 9 summarizes our main results for the dynamic panel estimations at quarterly frequency.<sup>65</sup> In the first two columns, we use the amount of corporate liquidity as the dependent variable. The first column reports a negative coefficient of inflation, which, however, is not significant at conventional levels. The second column displays a negative impact of the nominal interest rate on corporate liquidity holdings, which is significant on a 5% level. This coefficient suggests that, averaging across firms, a 1% increase in the nominal interest rate reduces liquidity holdings per firm by almost 1.4 million US\$ in the same quarter. In particular, our estimation results are consistent with proposition  $\mathcal{H}1$  derived in the context of the specific agency problem underlying our theoretical model. In both cases, we control for firm size (total assets), which - not surprisingly - has a positive effect on liquidity holdings.

The remaining columns of Table 9 have R&D expenses per firm as the dependent variable. The third column illustrates that inflation has a negative (causal) impact on firm-level investments in R&D; the coefficient is significant on a 5% level. Keeping the amount of total assets fixed, a 1% increase in inflation reduces R&D expenses per firm on average by 0.9 million US\$. Moreover, as evidenced by the positive coefficient on total assets, larger firms invest more in R&D. In view of the empirical evidence that larger firms have better outside financing opportunities, this indicates that R&D investments are constrained by a firm’s financing opportunities. Importantly, the fourth column demonstrates that the distortionary effect of inflation declines if we control for the amount of corporate liquidity holdings. We find that the coefficient of inflation is cut by one half and not significant any more at conventional levels. At the same time, an increase in liquid assets per firm enhances investments in superior technologies; the corresponding coefficient is significant on a 1% level.<sup>66</sup> In the next two columns of Table 9, we

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<sup>62</sup>For practical purposes, we impose one instrument for each variable and lag distance (collapse option), rather than one for each time period, variable, and lag distance in the case of the GMM system estimator. This restriction on the instrumental variable matrix reduces efficiency, but increases the number of overidentifying restrictions which are used to test for the validity of the instruments (Hansen-test). Moreover, we limit the number of lags to six in the case of the Arellano-Bond estimator.

<sup>63</sup>In addition, the GMM system estimator allows for the Hansen-test of overidentifying restrictions even in the presence of heteroscedasticity-robust standard errors.

<sup>64</sup>As explained above, inflation and the nominal interest rate are considered as exogenous variables. The microeconomic variables are considered as (potentially) endogenous.

<sup>65</sup>The same qualitative results obtain also for OLS or static fixed effects estimations. However, both estimators are inconsistent in our setting due to the presence of aggregate variables in a dynamic disaggregate panel framework.

<sup>66</sup>We note that all qualitative results are also robust to the inclusion of industry- instead of firm-fixed effects. Results are available from the authors upon request.

repeat the same exercise, using yield on corporate bonds rather than inflation as the measure of nominal fluctuations. The nominal interest rate has a negative impact on firm-level R&D expenses; the corresponding coefficient is significant on a 1% level. Again, the effect is smaller in absolute terms and loses significance at conventional levels if firm-level liquid assets are controlled for. Finally, in the last column of Table 9, again resorting to the rate of inflation as the key explanatory variable, we include the S&P credit rating index as an additional control variable. This reduces the effective sample to 7482 observations since the rating is only available for a subset of firms. The coefficient of the index reveals that a downgrading in the credit rating reduces R&D expenditures. Yet, the coefficient is not significant at conventional levels. However, the adverse effect of inflation on R&D expenses increases and is even significant at a 1% level for the relevant subset of firms. Overall, the quarterly firm-level results exactly confirm our specific theoretical mechanism in that increases in inflation or interest rates reduce investments in advanced projects (R&D). Moreover, as demonstrated by the differential coefficient pattern depending on whether corporate liquidity holdings are switched on or off as a control variable, the latter are indeed a quantitatively relevant transmission channel for the effect of nominal fluctuations on the composition of firms' investment portfolios.

In Table 10, we report the firm-level evidence for data recorded at yearly frequency. The outline of the results follows the same logic as for Table 9. The first two columns reveal that an increase in either inflation or nominal interest rates substantially reduces corporate liquidity holdings. The two relevant coefficients are both significant on a 5% level. Moreover, inflation reduces R&D investments per firm. At a yearly frequency, the corresponding coefficient suggests that a 1% increase in inflation reduces a firm's R&D expenses on average by 45 million US\$.<sup>67</sup> The distortionary effect of inflation declines by 21% and becomes insignificant if we additionally control for liquidity holdings per firm. The direct effect of corporate liquidity holdings on R&D is close to the one at the quarterly frequency and significant at a 1% level. In contrast to the quarterly frequency, the coefficient of the nominal interest rate in the R&D regression, though still negative, is not significant at conventional levels. It even switches its sign if we control for liquid assets. In the last two columns of Table 10, we systematically exploit the information of the S&P credit rating. Specifically, we split the sample into two subsets: (i) firms with a "sound" credit ranking (below 12) and (ii) firms with a "poor" one (above 12).<sup>68</sup> Following the logic of our model, one would expect that the negative impact of inflation on R&D is more pronounced for firms with worse access to external finance since precautionary holding of marketable assets for the purpose of insuring against liquidity risk becomes more important. Indeed, columns seven and eight display that the distorting impact of inflation is five times higher for firms with a poor credit ranking. Furthermore, a deterioration in the credit rating has a negative direct effect on R&D investments for the subset of firms with a relatively bad credit rating, while the effect is not significant for the subset of better-rated firms.

Summing up, the firm-level results show that inflation has a negative impact on firm-level investments in superior technologies. However, this effect disappears if we correctly control for corporate holdings of cash and marketable securities and individual firms' outside financing opportunities. Thus, the impact of inflation on compositional investment decisions at the firm-

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<sup>67</sup>We employ the Arellano-Bond estimator in this case since the coefficient of the lagged dependent variable is close to one, indicating problems with the stationarity of R&D at that frequency, if we employ the Blundell-Bond estimator.

<sup>68</sup>An index above 12 is usually considered to indicate a "bad" credit ranking (compare Computstat).

level is actually due to variations in a firm's corporate liquidity holdings and outside financing opportunities. Together with the results from the previous industry-level analysis, the empirical firm-level findings provide strong evidence in favor of the microeconomic mechanism underlying our propositions regarding the aggregate relation between inflation and TFP-growth at business cycle frequency.

## 6 Concluding remarks

In this paper, we have proposed a business cycle model where an agency problem gives rise to the theoretical prediction that increases the rate of inflation and the nominal interest rate are negatively related to realized levels of and thus also the growth in aggregate productivity. A causal effect running from the nominal interest rate distortions associated with higher levels of inflation to TFP has been rationalized on the basis of the former variables' impact on the composition of aggregate investment which can be sunk into different technologies. The calibrated model has been simulated in order to gain insights on its specific cyclical implications and to confront it with US business cycle statistics. In particular, we conclude that monetary policy, both in terms of systematic effects and unexpected innovations, has a non-negligible effect on aggregate productivity. Finally, by means of an extensive empirical analysis of aggregate as well as disaggregate data, we have provided robust empirical evidence underpinning the empirical relevance and quantitative importance of the predictions derived from the theoretical model. Most prominent among these is the proposition that corporate liquidity holdings are crucial for hedging investments into superior, but risky projects, and that, correspondingly, fluctuations in the relevant liquidity premium have a compositional effect on firms' investment decisions.

## A Tables

## B Appendix

### B.1 Implementation and discussion of second best policy

Aggregating over the advanced sector firms, we can derive two measures of aggregate liquidity demand. The first one is relevant if the second best policy should be feasible for each individual firm, but liquidity provision is organized in a way that disregards the scope for risk sharing across firms:

$$\bar{D}_t = \hat{\xi}_t^* P_t^z \tilde{y}_t^z \quad (34a)$$

In contrast, the second measure of overall liquidity demand is relevant if liquidity risk can be pooled across firms:

$$D_t^* = \left[ \int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t \right] P_t^z \tilde{y}_t^z < \bar{D}_t \quad (34b)$$

It is clear that this latter concept requires some form of financial intermediation.

Now, drawing on Holmstrom and Tirole (1998), we turn to the institutional details supporting the implementation of the second best policy derived in Section 3.5. One possibility is to have the financial intermediary initially extend the amount  $MC_t^z(\cdot)\tilde{y}_t^z - E_t$  to the entrepreneur together with an *irrevocable line of credit* of maximum size  $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$  to be drawn from as needed at the interim stage. Given our assumptions on the details of the moral hazard problem which does not envisage distraction of resources on the part of the entrepreneur, this line of credit implements the second best solution as long as the credit line, irrespective of the amount  $\xi_t P_t^z \tilde{y}_t^z \leq \hat{\xi}_t^* P_t^z \tilde{y}_t^z$  of liquidity actually requested, is provided free of charge. Since the firms' liquidity shocks are independent, the aggregate amount of resources needed to cover the advanced sector's refinancing needs at the interim stage is then given by  $D_t^*$ . At the level of an individual advanced sector firm, an alternative would be via a *liquidity covenant* which involves the financial intermediary initially extending the amount  $[1 + (P_t^z/MC_t^z(\cdot))\hat{\xi}_t^*]MC_t^z(\cdot)\tilde{y}_t^z - E_t$  to the entrepreneur, whereby the requirement is imposed that the amount  $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$  is not sunk in the project but kept in the form of readily marketable assets. However, at the aggregate level across all advanced sector firms, implementation of the second best policy via liquidity covenants is seen to require strictly more resources  $\bar{D}_t > D_t^*$  because liquidity is kept separately at each firm, thus forgoing the potential to pool liquidity across firms.<sup>69</sup>

Above discussion highlights that not only the aggregate supply of liquidity, but also its ex post distribution matter. Specifically, the scarcity of the aggregate supply of liquidity stems from households' limited asset market participation because this structure implies that no additional resources can be mobilized between the time of financial contracting (*stage one*) and

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<sup>69</sup>In the benchmark section of their paper which features an exogenous supply of liquidity, Holmstrom and Tirole (1998) establish equivalence of the two methods of providing liquidity. This result stems from the fact that their economy allows for a technology ("cash") to transfer wealth across the stages of the financial contracting problem and the additional assumption that "cash" is not scarce. Conversely, in our economy "cash" is available, but its (limited) supply is determined in general equilibrium via households' financial deposits and monetary policy. Importantly then, liquidity is costly (it has a price  $\tilde{R}_t > 1$ ), and agents have an incentive to economize on its usage. The consequence is that intermediated credit lines and liquidity holdings on behalf of the firms are no longer equivalent.

the time when corporate profits as well as households' purchases are realized (*stage three*). The shadow price for such scarce liquidity is the nominal interest rate  $\tilde{R}_t$ ; indeed, even if households' market participation were possible at the interim stage, a strictly positive net interest rate  $(\tilde{R}_t - 1)$  would be sufficient to limit the financial intermediary's capability to provide additional funds due to the (opportunity) costs of doing so. On the other hand, given that liquidity is costly, also its distribution matters, which becomes apparent when comparing the intermediated credit line with the decentralized liquidity covenant. The problem with the latter is that firms with low realizations for their idiosyncratic shock end up holding costly liquidity which they do not need, while, at the same time, firms with high shocks need to terminate their projects. Hence, ex post a redistribution of liquidity would be desirable. This insight again highlights the key advantage of a financial intermediary, who can pool liquidity risk across firms by means of a system of credit lines, over the institution of a liquidity covenant: The latter's value cannot be conditioned on the ex post realization of an individual firm's liquidity needs, while the credit line actually called by the firm varies in line with the idiosyncratic shock up to the cutoff  $\hat{\xi}_t^*$ .

It has been established above that a simple liquidity covenant cannot implement the second best outcome. Given our empirical interest, the question arises whether there is a second best policy that features firms (rather than the intermediary) holding liquidity. We now give an example for such a policy. For that purpose, first define a number  $\check{\xi}_t$  which is implicitly given by  $D_t^* = \check{\xi}_t P_t^z \tilde{y}_t^z$ ; then, a policy of the desired kind is constructed as follows: At stage one, the intermediary extends the amount  $[1 + (P_t^z / MC_t^z(\cdot))\check{\xi}_t] MC_t^z(\cdot) \tilde{y}_t^z - E_t$  to the entrepreneur. The financial contract further stipulates that the amount  $\check{\xi}_t P_t^z \tilde{y}_t^z$  must be held in the form of liquid assets. The firm will then invest up to the maximum admissible scale  $MC_t^z(\cdot) \tilde{y}_t^z - E_t$  and deposit its liquid assets with the intermediary (at zero interest). Now, at stage two, when hit by a liquidity shock  $\xi_t$ , the firm must first use up its own asset position of  $\check{\xi}_t P_t^z \tilde{y}_t^z$ ; only then can it approach the intermediary for additional funds, which the latter will residually provide up to the second best quantity  $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$ . The intermediary is able to provide this liquidity by calling idle funds from those firms who receive shocks  $\xi_t < \check{\xi}_t$ . Obviously, this policy replicates the second best in terms of both the initial investment scale and the cutoff  $\hat{\xi}_t^*$ . Thus, it only remains to check whether above arrangement is feasible, which is the case since, from the definition of  $\check{\xi}_t$ , the supply of and demand for liquidity are equal at the aggregate level:  $P_t^z \tilde{y}_t^z \check{\xi}_t = D_t^* = P_t^z \tilde{y}_t^z \int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t$ . Further variations on the institutional structure implementing the second best, involving advanced sector firms holding assets other than cash (e.g. corporate debt issued by the basic sector firms) as well as liquid assets earning non-zero rates of return, are possible.

## B.2 TFP accounting

Our model assumes that firms can employ two different Cobb-Douglas technologies which are homogenous in their two respective input factors, capital and labor:  $\varphi(k_t, l_t^k) = (k_t)^{\alpha^k} ((1 + \gamma)^t l_t^k)^{(1-\alpha^k)}$  and  $f(z_t, l_t^z) = (z_t)^{\alpha^z} ((1 + \gamma)^t l_t^z)^{(1-\alpha^z)}$ . Thus, the equations determining sectoral outputs read  $y_t^k = \mathcal{A}_t \varphi(k_t, l_t^k)$  and  $y_t^z = G(\hat{\xi}_t^*) \tilde{y}_t^z = \mathcal{V}_t G(\hat{\xi}_t^*) f(z_t, l_t^z)$ . Totally differentiating both equations and dropping time subscripts yields:

$$\begin{aligned} dy^k &= d\mathcal{A}\varphi(k, l^k) + \mathcal{A}(\varphi_k(k, l^k)dk + \varphi_l(k, l^k)dl^k) \\ dy^z &= \left( d\mathcal{V}G(\cdot) + \mathcal{V}g(\cdot)d\hat{\xi}^* \right) f(z, l^z) + \mathcal{V}G(\cdot)(f_z(z, l^z)dz + f_l(z, l^z)dl^z) \end{aligned}$$

Dividing these equations by  $\mathcal{A}\varphi(k, l^k)$  and  $\mathcal{V}G(\cdot)f(z, l^z)$ , respectively, one obtains the approximate percentage deviations (denoted by hats) of the two intermediate outputs:

$$\begin{aligned}\widehat{y^k} &= \widehat{\mathcal{A}} + \alpha^k \widehat{k} + (1 - \alpha^k) \widehat{l^k} \\ \widehat{y^z} &= \widehat{\mathcal{V}} + \omega_{\xi^*}^G \widehat{\xi^*} + \alpha^z \widehat{z} + (1 - \alpha^z) \widehat{l^z},\end{aligned}$$

where  $\widehat{x} \equiv \frac{dx}{x}$  and where  $\omega_{\xi^*}^G = \frac{g(\xi^*)\xi^*}{G(\xi^*)}$  denotes the elasticity of the survival probability with respect to the cutoff value for liquidity shocks  $\xi^*$ . Since we measure TFP-growth by the part of output growth which is not explained by the growth of the input factors, it follows that productivity growth in the basic sector is:

$$\widehat{TFP^k} = \widehat{y^k} - \alpha^k \widehat{k} - (1 - \alpha^k) \widehat{l^k} = \widehat{\mathcal{A}},$$

where the first equality is an implication of the definition of TFP as the Solow residual. Similarly, for the advanced technology, we get:

$$\widehat{TFP^z} = \widehat{y^z} - \alpha^z \widehat{z} - (1 - \alpha^z) \widehat{l^z} = \widehat{\mathcal{V}} + \omega_{\xi^*}^G \widehat{\xi^*}$$

From these equations, we can deduce overall TFP-growth as the weighted sum of productivity growth of the different technologies. Specifically, from (6), aggregate output is given by a CES aggregation of the intermediate outputs produced with the different technologies. Aggregate output growth can then be expressed as the composite of technology-specific growth rates:

$$\begin{aligned}\widehat{y} &= \underbrace{\zeta^{\frac{1}{\rho}} \left( \frac{y^k}{y} \right)^{\frac{\rho-1}{\rho}}}_{\equiv \omega_{yk}^y} \widehat{y^k} + \underbrace{(1 - \zeta)^{\frac{1}{\rho}} \left( \frac{y^z}{y} \right)^{\frac{\rho-1}{\rho}}}_{\equiv \omega_{yz}^y} \widehat{y^z} \\ &= \omega_{yk}^y \widehat{y^k} + \omega_{yz}^y \widehat{y^z}\end{aligned}$$

Hence, combining the expression for aggregate output growth with the results for the intermediate output growth rates, aggregate TFP-growth, i.e. innovations to aggregate output growth which cannot be attributed to changes in capital or labor growth, is measured as:

$$\begin{aligned}\widehat{TFP} = \widehat{\mathcal{T}} &= \widehat{y} - \omega_{yk}^y \left( \alpha^k \widehat{k} + (1 - \alpha^k) \widehat{l^k} \right) - \omega_{yz}^y \left( \alpha^z \widehat{z} + (1 - \alpha^z) \widehat{l^z} \right) \\ &= \omega_{yk}^y \widehat{TFP^k} + \omega_{yz}^y \widehat{TFP^z} \\ &= \omega_{yk}^y \widehat{\mathcal{A}} + \omega_{yz}^y \left( \widehat{\mathcal{V}} + \omega_{\xi^*}^G \widehat{\xi^*} \right)\end{aligned}$$

### B.3 Competitive equilibrium relations

We can derive a set of relations that characterize a competitive equilibrium at the aggregate level. Specifically, for  $\tilde{R}_t > 1$ , the household's cash constraint (1b) is binding and we can aggregate over households and entrepreneurs to obtain a condition relating aggregate consumption and investment to agents' nominal asset holdings:

$$Q_t + \theta[W_t^{k,H} h_t^{k,H} + W_t^{z,H} h_t^{z,H}] + (1 - \eta)A_t = P_t[c_t + x_t], \quad (35)$$

where  $c_t = c_t^H + (1 - \eta)c_t^E$ . Then, the evolution of nominal wealth held by households is determined via the nominal budget constraint (1c) and the binding cash constraint (1b):

$$M_{t+1} = \tilde{R}_t[M_t - Q_t + J_t] + \Upsilon_t + R_t^k k_t + R_t^z z_t + (1 - \theta)[W_t^{k,H} h_t^{k,H} + W_t^{z,H} h_t^{z,H}], \quad (36)$$

where we note that  $\Upsilon_t = D_t + E_t$ . This relation stipulates that, at the end of any given period, the nominal resources  $D_t + E_t$  lost due to liquidity shocks are rechannelled to the household sector. Accordingly then, while the termination of projects implies that the production of real output is curbed, the amount of nominal resources ("money") circulating is unaffected by liquidity shocks. Now, making use (i) of a zero-profit condition for firms in the basic sector, firms in the advanced sector (net of entrepreneurial rents  $\tilde{\Pi}_t^F(\hat{\xi}_t^*)E_t$ ) and the financial intermediary, (ii) of the financial market clearing condition (5), and (iii) of the aggregate cash constraint (35), one obtains:

$$M_{t+1} = M_t + \mathcal{J}_t + \left\{ (1 - \eta)A_t - [W_t^{k,E} h_t^{k,E} + W_t^{z,E} h_t^{z,E} + (\tilde{\Pi}_t^F(\hat{\xi}_t^*) - 1)E_t] \right\} \quad (37)$$

This relation has the intuitive interpretation that the evolution of nominal household wealth is governed by cash injections  $\mathcal{J}_t$  and the net cash flow from the entrepreneurial sector (entrepreneurial consumption expenditure minus retained earnings) to the household sector. The evolution of nominal wealth in the entrepreneurial sector itself follows:

$$A_{t+1} = \tilde{\Pi}_t^F(\hat{\xi}_t^*)E_t + (1 - \theta)[W_t^{k,E} h_t^{k,E} + W_t^{z,E} h_t^{z,E}], \quad (38)$$

where  $E_t = \eta A_t + \theta[W_t^{k,E} h_t^{k,E} + W_t^{z,E} h_t^{z,E}]$ . In order to derive a convenient expression for the evolution of aggregate wealth, we add equations (36) and (38) and employ the zero-profit condition mentioned above as well as condition (5) to obtain:

$$M_{t+1} + A_{t+1} - (D_t + E_t) = P_t y_t, \quad (39)$$

which gives immediately rise to a modified quantity relation:

$$P_t = \frac{M_{t+1} + A_{t+1} - (D_t + E_t)}{y_t} \quad (40)$$

Again, this equation allows for an intuitive interpretation, namely that the contemporaneous price level  $P_t$  is determined as the ratio of nominal resources channelled through the goods market to aggregate output.<sup>70</sup>

## B.4 Calibration

The set of parameters characterizing the economy can be organized into the following sets: (i) preference parameters  $\beta, \sigma, \mu, \nu, \psi$ , (ii) technology parameters  $\alpha_k, \alpha_z, \gamma, \delta, \phi, \theta, \Omega, \eta$ , (iii) parameters relevant for the economy's sectoral composition  $\rho, \zeta, \chi, b$  as well as the relevant

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<sup>70</sup>To see this, note that the agents' end-of-period wealth  $M_{t+1} + A_{t+1}$  is effectively generated via firm profits whose generation requires transactions on the goods market; from this amount, the nominal resources which are absorbed by liquidity needs and later redistributed to the household sector must be deduced.

moments  $\mu_\xi$  and  $\sigma_\xi$  of the liquidity shock distribution  $G(\cdot)$ , and (iv) parameters characterizing the relevant stochastic processes  $\rho_j, \rho_a, \rho_v, \rho_{av}, \sigma_j, \sigma_a, \sigma_v$ .

The parameters we set beforehand are the coefficient of relative risk aversion  $\sigma = 2$ , the utility function's curvature  $\nu = 2.67$  with respect to labor<sup>71</sup> in the GHH case and the fraction  $\theta$  of the firms' wage bill that needs to be paid in advance; we assume a benchmark value of  $\theta = 0.5$ , thus striking a balance between the two polar cases of zero and one. The parameters  $\Omega$  and  $\eta$  determine the relative importance of the entrepreneurs in the economy with respect to their labor supply and their accumulated wealth; in view of the parametrizations employed in the literature, we set  $\Omega = 0.95$  and  $\eta = 0.97$ .<sup>72</sup>

As to the parameters determined from the data, we first resort to relevant time series for the US at quarterly frequency (1959:1-2006:2) which were obtained from the Bureau of Economic Analysis and the Bureau of Labor Statistics. Specifically, we set  $\gamma = 0.0037$  to match the average growth rate of real output per hour worked over our sample of 0.37% per quarter and  $\beta = 0.98$  to match the average implied real interest rate - the difference between the nominal interest rate and the rate of inflation - of 2.7% over this sample. The parameters  $\psi = 4$  (GHH) and  $\mu = 0.167$  (Cobb-Douglas), respectively, are calibrated to be on average consistent with the consumption-leisure FOC (4), while  $\alpha^k = \alpha^z = \alpha = 0.31$  are set to match the labor share of income.<sup>73</sup> Finally,  $\delta = 0.0112$  is pinned down such as to match the average consumption of fixed capital. The adjustment cost parameter  $\phi = 8$ , which works on the sectoral capital stocks, is determined such as to match the empirical volatility of aggregate investment of 5.60%.

The sectoral composition of the economy is mainly determined by the parameters  $\rho, \zeta$  and  $\chi$ , which we calibrate from industry data, as well as by the agency cost parameter  $b$  and the moments  $\mu_\xi, \sigma_\xi$  of the liquidity shock distribution  $G(\cdot)$ , which is assumed to be lognormal. The parameters  $b = 0.15, \mu_\xi = -0.5, \sigma_\xi = 0.5$  are jointly calibrated such as to generate a steady state with (i) a survival rate of 81% in the advanced sector (corresponding to a failure rate of 5% across all firms) and (ii) a share of corporate liquidity in overall short term credit of  $\frac{D}{D+\theta WL}$  of one third. In order to pin down the parameters  $\rho$  and  $\zeta$ , we recover estimates for these parameters using annual industry level data from the UNIDO industry database covering the period 1977-1997. These data provide disaggregate information on value added and output prices at industry level according to the Standard Industrial Classification (SIC) system; we drop the government and the financial sector as well as industries with missing data and are left with 36 industries (see Table 3). We organize these remaining industries into two subaggregates, whereby the sorting criterion is the standard deviation of each industry's growth rate of value added over time. We interpret these subaggregates as the two sectors in our model economy and use the associated relative prices to infer the parameters of interest from equations (7). In particular, from total differentiation of these relative demand schedules, one obtains (with hats

<sup>71</sup>The corresponding labor supply elasticity is  $\frac{1}{\nu-1} = 0.6$ .

<sup>72</sup>Compare e.g. Bernanke, Gertler and Gilchrist (1999) and the references therein.

<sup>73</sup>The restriction  $\alpha_k = \alpha_z$  is imposed due to the lack of informative data. Note also that we treat entrepreneurs' wage earnings as part of the overall labor earnings and that the labor share needs to be adjusted since, due to the firms' advance financing requirement, part of the income is used to pay interest; specifically, we exploit the following steady state relation: labor share =  $\frac{(1-\alpha)}{[1+\theta(\bar{R}-1)]}$ .

denoting relative changes):

$$\widehat{\left(\frac{y^i}{y}\right)} = -\rho \widehat{\left(\frac{P^i}{P}\right)}$$

This allows to isolate the elasticity of substitution  $\rho = 1.66$ ; then, using this information in equations (7) and (9), the relative sectoral weights  $\zeta = 0.73$  and  $(1 - \zeta) = 0.27$  as well as the elasticities of aggregate output with respect to the sectoral intermediate output levels:

$$\omega_{yk}^y = \zeta^{\frac{1}{\rho}} \left(\frac{y^k}{y}\right)^{\frac{\rho-1}{\rho}} \quad \text{and} \quad \omega_{yz}^y = (1 - \zeta)^{\frac{1}{\rho}} \left(\frac{y^z}{y}\right)^{\frac{\rho-1}{\rho}}$$

are straightforwardly obtained. The productivity difference parameter across the two subaggregates is estimated from the data as  $\chi = 2.97$ . Similarly, we exploit the time series properties of value added in the two industrial subaggregates in order to parametrize the relevant stochastic processes for technology. We directly infer  $\rho_a = 0.79$ ,  $\rho_v = 0.66$  and  $\rho_{av} = 0.67$ ; the volatility parameters  $\sigma_a$  and  $\sigma_v$  are also estimated from the relevant value added data, but adjusted (keeping relative values constant) to be consistent with the volatility of aggregate TFP, which yields  $\sigma_a = 0.0046$  and  $\sigma_v = 0.0083$ . Finally,  $\rho_j = 0.875$  and  $\sigma_j = 0.0033$  are calibrated from the empirical process for M2.

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Table 2: Cyclical behavior of the US economy, quarterly data 1964:1-2006:2

| Variable        | SD%  | Cross-correlation of real output (GDP) with |       |       |       |       |       |       |       |       |       |       |
|-----------------|------|---------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                 |      | x(-5)                                       | x(-4) | x(-3) | x(-2) | x(-1) | x     | x(+1) | x(+2) | x(+3) | x(+4) | x(+5) |
| GDP             | 1.54 | 0.04                                        | 0.26  | 0.47  | 0.69  | 0.87  | 1.00  | 0.87  | 0.69  | 0.47  | 0.26  | 0.04  |
| HOURS           | 1.74 | -0.15                                       | 0.03  | 0.24  | 0.47  | 0.70  | 0.88  | 0.91  | 0.83  | 0.70  | 0.51  | 0.30  |
| INV             | 5.60 | 0.10                                        | 0.25  | 0.43  | 0.61  | 0.78  | 0.93  | 0.82  | 0.63  | 0.41  | 0.18  | -0.06 |
| Rcorp           | 0.68 | -0.55                                       | -0.56 | -0.55 | -0.48 | -0.33 | -0.17 | -0.06 | 0.03  | 0.09  | 0.13  | 0.16  |
| $\Delta$ M2     | 0.69 | 0.17                                        | 0.14  | 0.06  | -0.04 | -0.17 | -0.30 | -0.38 | -0.36 | -0.28 | -0.25 | -0.15 |
| $\Delta$ GDPDEF | 0.29 | -0.40                                       | -0.35 | -0.24 | -0.10 | 0.02  | 0.14  | 0.29  | 0.40  | 0.48  | 0.50  | 0.45  |
| TFP             | 0.81 | 0.38                                        | 0.52  | 0.61  | 0.65  | 0.62  | 0.58  | 0.25  | -0.01 | -0.26 | -0.39 | -0.50 |
| $\Delta$ TFP    | 0.60 | 0.17                                        | 0.19  | 0.12  | 0.06  | -0.04 | -0.05 | -0.45 | -0.36 | -0.33 | -0.18 | -0.14 |

  

| Variable        | SD%  | Cross-correlation of inflation ( $\Delta$ GDPDEF) with |       |       |       |       |       |       |       |       |       |       |
|-----------------|------|--------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                 |      | x(-5)                                                  | x(-4) | x(-3) | x(-2) | x(-1) | x     | x(+1) | x(+2) | x(+3) | x(+4) | x(+5) |
| GDP             | 1.54 | 0.45                                                   | 0.50  | 0.48  | 0.40  | 0.29  | 0.14  | 0.02  | -0.10 | -0.24 | -0.35 | -0.40 |
| HOURS           | 1.74 | 0.40                                                   | 0.49  | 0.50  | 0.48  | 0.44  | 0.37  | 0.22  | 0.07  | -0.07 | -0.20 | -0.30 |
| INV             | 5.60 | 0.37                                                   | 0.41  | 0.42  | 0.33  | 0.23  | 0.15  | 0.04  | -0.14 | -0.26 | -0.38 | -0.41 |
| Rcorp           | 0.68 | -0.36                                                  | -0.26 | -0.14 | -0.00 | 0.15  | 0.28  | 0.37  | 0.46  | 0.48  | 0.43  | 0.41  |
| $\Delta$ M2     | 0.69 | -0.20                                                  | -0.26 | -0.28 | -0.29 | -0.27 | -0.23 | -0.21 | -0.03 | 0.00  | 0.10  | 0.22  |
| $\Delta$ GDPDEF | 0.29 | -0.03                                                  | 0.23  | 0.22  | 0.28  | 0.47  | 1.00  | 0.47  | 0.28  | 0.22  | 0.23  | -0.03 |
| TFP             | 0.81 | 0.26                                                   | 0.19  | 0.14  | 0.00  | -0.19 | -0.35 | -0.36 | -0.38 | -0.41 | -0.42 | -0.35 |
| $\Delta$ TFP    | 0.60 | -0.15                                                  | -0.08 | -0.08 | -0.18 | -0.25 | -0.23 | -0.01 | -0.02 | -0.05 | -0.01 | 0.09  |

  

| Variable        | SD%  | Cross-correlation of yield on corporate bonds (Rcorp) with |       |       |       |       |       |       |       |       |       |       |
|-----------------|------|------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                 |      | x(-5)                                                      | x(-4) | x(-3) | x(-2) | x(-1) | x     | x(+1) | x(+2) | x(+3) | x(+4) | x(+5) |
| GDP             | 1.54 | 0.16                                                       | 0.13  | 0.09  | 0.03  | -0.05 | -0.17 | -0.33 | -0.48 | -0.54 | -0.56 | -0.54 |
| HOURS           | 1.74 | 0.27                                                       | 0.27  | 0.26  | 0.23  | 0.16  | 0.04  | -0.14 | -0.33 | -0.46 | -0.54 | -0.58 |
| INV             | 5.60 | 0.07                                                       | 0.06  | 0.06  | 0.04  | -0.01 | -0.09 | -0.24 | -0.44 | -0.53 | -0.54 | -0.54 |
| Rcorp           | 0.68 | -0.04                                                      | 0.16  | 0.39  | 0.61  | 0.83  | 1.00  | 0.83  | 0.61  | 0.39  | 0.16  | -0.04 |
| $\Delta$ M2     | 0.69 | -0.12                                                      | -0.14 | -0.13 | -0.13 | -0.13 | -0.13 | 0.03  | 0.24  | 0.33  | 0.33  | 0.35  |
| $\Delta$ GDPDEF | 0.29 | 0.41                                                       | 0.43  | 0.48  | 0.46  | 0.37  | 0.28  | 0.15  | 0.00  | -0.14 | -0.26 | -0.36 |
| TFP             | 0.81 | -0.17                                                      | -0.21 | -0.28 | -0.34 | -0.40 | -0.44 | -0.48 | -0.46 | -0.36 | -0.24 | -0.13 |
| $\Delta$ TFP    | 0.60 | -0.10                                                      | -0.06 | -0.09 | -0.09 | -0.07 | -0.06 | -0.05 | 0.02  | 0.13  | 0.17  | 0.15  |

All series except Rcorp,  $\Delta$  GDPDEF and  $\Delta$  TFP are in logs. All series have been Hodrick-Prescott filtered with a smoothing parameter of 1600. All statistics are based on quarterly data.

Table 3: Cyclical behavior of benchmark model economy

| Variable   | SD%  | Cross-correlation of real output (GDP) with |       |       |       |       |       |       |       |       |       |       |
|------------|------|---------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|            |      | x(-5)                                       | x(-4) | x(-3) | x(-2) | x(-1) | x     | x(+1) | x(+2) | x(+3) | x(+4) | x(+5) |
| GDP        | 1.16 | 0.52                                        | 0.58  | 0.65  | 0.75  | 0.86  | 1.00  | 0.86  | 0.75  | 0.65  | 0.58  | 0.52  |
| HOURS      | 1.27 | 0.25                                        | 0.26  | 0.27  | 0.28  | 0.29  | 0.55  | 0.44  | 0.36  | 0.30  | 0.25  | 0.20  |
| INV        | 5.48 | 0.48                                        | 0.56  | 0.65  | 0.77  | 0.93  | 0.74  | 0.59  | 0.47  | 0.37  | 0.30  | 0.23  |
| R          | 1.20 | 0.00                                        | 0.01  | 0.01  | 0.02  | 0.03  | -0.17 | -0.22 | -0.20 | -0.17 | -0.16 | -0.14 |
| $\Delta$ M | 0.68 | -0.43                                       | -0.46 | -0.51 | -0.56 | -0.62 | -0.57 | -0.50 | -0.44 | -0.38 | -0.34 | -0.29 |
| $\Delta$ P | 1.02 | -0.34                                       | -0.38 | -0.43 | -0.48 | -0.55 | -0.56 | -0.19 | -0.15 | -0.15 | -0.14 | -0.13 |
| TFP        | 0.85 | 0.29                                        | 0.35  | 0.43  | 0.53  | 0.67  | 0.58  | 0.48  | 0.38  | 0.30  | 0.24  | 0.20  |

  

| Variable   | SD%  | Cross-correlation of nominal interest rates ( $R$ ) with |       |       |       |       |       |       |       |       |       |       |
|------------|------|----------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|            |      | x(-5)                                                    | x(-4) | x(-3) | x(-2) | x(-1) | x     | x(+1) | x(+2) | x(+3) | x(+4) | x(+5) |
| GDP        | 1.16 | -0.14                                                    | -0.16 | -0.17 | -0.20 | -0.22 | -0.17 | 0.03  | 0.02  | 0.01  | 0.01  | 0.00  |
| HOURS      | 1.27 | -0.18                                                    | -0.19 | -0.23 | -0.25 | -0.31 | 0.20  | 0.09  | 0.02  | 0.07  | 0.02  | 0.06  |
| INV        | 5.48 | -0.14                                                    | -0.15 | -0.17 | -0.18 | -0.21 | 0.08  | 0.07  | 0.06  | 0.05  | 0.04  | 0.04  |
| R          | 1.20 | -0.05                                                    | 0.01  | -0.06 | 0.01  | -0.07 | 1.00  | -0.07 | 0.01  | -0.06 | 0.01  | -0.05 |
| $\Delta$ M | 0.68 | 0.25                                                     | 0.27  | 0.32  | 0.35  | 0.41  | -0.08 | -0.07 | -0.06 | -0.05 | -0.05 | -0.04 |
| $\Delta$ P | 1.02 | 0.18                                                     | 0.20  | 0.23  | 0.26  | 0.30  | 0.03  | -0.39 | -0.08 | 0.02  | -0.06 | 0.02  |
| TFP        | 0.85 | 0.02                                                     | 0.01  | 0.03  | 0.02  | 0.05  | -0.38 | 0.01  | 0.05  | 0.00  | 0.04  | -0.01 |

Statistics generated from theoretical moments.

Table 4: Cyclical and steady state behavior of alternative model economies

| Variable   | SD%  | Model without money shocks ( $\sigma_j = 0$ ): Cross-correlation of real output (GDP) with |       |       |       |       |       |       |       |       |       |       |
|------------|------|--------------------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|            |      | x(-5)                                                                                      | x(-4) | x(-3) | x(-2) | x(-1) | x     | x(+1) | x(+2) | x(+3) | x(+4) | x(+5) |
| GDP        | 0.88 | 0.40                                                                                       | 0.47  | 0.55  | 0.66  | 0.80  | 1.00  | 0.80  | 0.66  | 0.55  | 0.47  | 0.40  |
| HOURS      | 0.87 | -0.09                                                                                      | -0.11 | -0.15 | -0.20 | -0.26 | 0.36  | 0.26  | 0.19  | 0.14  | 0.10  | 0.07  |
| INV        | 4.43 | 0.40                                                                                       | 0.48  | 0.59  | 0.74  | 0.94  | 0.69  | 0.51  | 0.38  | 0.28  | 0.20  | 0.14  |
| R          | 0.06 | 0.24                                                                                       | 0.29  | 0.37  | 0.47  | 0.61  | 0.66  | 0.40  | 0.30  | 0.15  | 0.12  | 0.02  |
| $\Delta M$ | 0.00 | -0.25                                                                                      | -0.26 | -0.27 | -0.29 | -0.30 | -0.32 | -0.34 | -0.37 | -0.41 | -0.44 | -0.47 |
| $\Delta P$ | 0.55 | -0.08                                                                                      | -0.10 | -0.13 | -0.18 | -0.23 | -0.30 | 0.32  | 0.23  | 0.18  | 0.13  | 0.10  |
| TFP        | 0.77 | 0.41                                                                                       | 0.50  | 0.61  | 0.76  | 0.96  | 0.71  | 0.53  | 0.40  | 0.30  | 0.23  | 0.18  |

  

| Variance decomposition and selected contemporaneous correlations |                |                |                                |                |                |                                 |        |
|------------------------------------------------------------------|----------------|----------------|--------------------------------|----------------|----------------|---------------------------------|--------|
| Variable                                                         | SD% regime 1   |                | % attributable to money shocks | SD% regime 2   |                | % increase due to active policy |        |
|                                                                  | $\sigma_j > 0$ | $\sigma_j = 0$ |                                | $\sigma_j > 0$ | $\sigma_j = 0$ |                                 |        |
| GDP                                                              | 1.16           | 0.88           | 24.24                          | 1.30           | 1.05           | 11.88                           | 19.93  |
| HOURS                                                            | 1.27           | 0.87           | 31.71                          | 1.43           | 1.09           | 12.54                           | 25.36  |
| INV                                                              | 5.48           | 4.43           | 19.20                          | 5.77           | 4.78           | 5.29                            | 8.00   |
| R                                                                | 1.20           | 0.06           | 95.00                          | 1.28           | 0.47           | 7.16                            | 676.55 |
| $\Delta M$                                                       | 0.68           | 0.00           | 100.00                         | 0.80           | 0.43           | 17.89                           | N/A    |
| $\Delta P$                                                       | 1.02           | 0.55           | 45.89                          | 1.08           | 0.67           | 6.77                            | 21.57  |
| TFP                                                              | 0.85           | 0.77           | 9.34                           | 0.88           | 0.80           | 3.23                            | 3.91   |
| $\rho(\tilde{R}, y)$                                             | -0.17          | 0.66           | -                              | -0.27          | -0.35          | -                               | -      |
| $\rho(\hat{\xi}^*, y)$                                           | 0.19           | -0.47          | -                              | 0.29           | 0.39           | -                               | -      |
| $\rho(\tilde{R}, \hat{\xi}^*)$                                   | -0.99          | -0.71          | -                              | -0.99          | -0.98          | -                               | -      |
| $\rho(\tilde{R}, \mathcal{T})$                                   | -0.38          | 0.70           | -                              | -0.44          | -0.21          | -                               | -      |

  

| Steady state values and selected contemporaneous correlations |                 |                       |                 |                |                 |                 |
|---------------------------------------------------------------|-----------------|-----------------------|-----------------|----------------|-----------------|-----------------|
| Variable                                                      | Friedman rule   | $mg^* = (1 + \gamma)$ | $mg^* = 1.0167$ | $mg^* = 1.05$  | $mg^* = 1.1$    | $mg^* = 1.2$    |
|                                                               | $\pi^* = -2.42$ | $\pi^* = 0.00$        | $\pi^* = 1.31$  | $\pi^* = 4.74$ | $\pi^* = 10.11$ | $\pi^* = 21.69$ |
| $\tilde{R} - 1$                                               | 0.0000          | 0.0248                | 0.0383          | 0.0734         | 0.1284          | 0.2471          |
| $z/k$                                                         | 0.1587          | 0.1522                | 0.1488          | 0.1403         | 0.1282          | 0.1061          |
| $d$                                                           | 0.0730          | 0.0676                | 0.0649          | 0.0583         | 0.0495          | 0.0352          |
| $d/y$                                                         | 0.1532          | 0.1489                | 0.1467          | 0.1408         | 0.1320          | 0.1147          |
| $d/(d + \theta wL)$                                           | 0.3457          | 0.3420                | 0.3399          | 0.3343         | 0.3253          | 0.3050          |
| $G$                                                           | 0.8301          | 0.8170                | 0.8098          | 0.7908         | 0.7602          | 0.6927          |
| $y^z/y^k$                                                     | 0.3919          | 0.3699                | 0.3584          | 0.3301         | 0.2899          | 0.2186          |
| $\mathcal{T}$                                                 | 1.2001          | 1.1889                | 1.1824          | 1.1655         | 1.1395          | 1.0859          |
| $\rho(\tilde{R}, y)$                                          | -0.17           | -0.17                 | -0.17           | -0.17          | -0.17           | -0.17           |
| $\rho(\hat{\xi}^*, y)$                                        | 0.18            | 0.19                  | 0.19            | 0.19           | 0.19            | 0.19            |
| $\rho(\tilde{R}, \hat{\xi}^*)$                                | -0.97           | -0.98                 | -0.99           | -0.99          | -0.99           | -0.99           |
| $\rho(\tilde{R}, \mathcal{T})$                                | -0.35           | -0.37                 | -0.38           | -0.40          | -0.43           | -0.49           |

Statistics generated from theoretical moments.

Table 5: USA: Sectoral volatility and mean of growth in value added per worker

| Industries                          | volatility  | ranking | average growth | ranking |
|-------------------------------------|-------------|---------|----------------|---------|
| Petroleum refineries                | 22.41135418 | 1       | 8.718858009    | 4       |
| Non-ferrous metals                  | 14.82056985 | 2       | 6.70920077     | 14      |
| Iron and Steel                      | 13.20761732 | 3       | 4.28101271     | 26      |
| Wood products, except furniture     | 12.33161156 | 4       | 7.080945619    | 13      |
| Professional & scientific equipment | 11.82739193 | 5       | 9.520253349    | 3       |
| Leather products                    | 10.80728372 | 6       | 3.355740195    | 28      |
| Industrial chemicals                | 9.80919931  | 7       | 6.565964224    | 17      |
| Tobacco                             | 9.466520079 | 8       | 9.765847611    | 2       |
| Plastic products                    | 9.047342577 | 9       | 11.40471846    | 1       |
| Misc. Petroleum and coal products   | 8.966026705 | 10      | 7.523389904    | 8       |
| Transport equipment                 | 8.93003486  | 11      | 6.708187212    | 15      |
| Pottery, china, earthenware         | 8.753001453 | 12      | 6.344808742    | 18      |
| Machinery, except electrical        | 8.447901686 | 13      | 7.217618028    | 11      |
| Footwear, except rubber or plastic  | 7.94506906  | 14      | 0.592402327    | 29      |
| Machinery, electric                 | 7.771043776 | 15      | 7.865959786    | 6       |
| Furniture, except metal             | 7.139279992 | 16      | 7.311662001    | 10      |
| Paper and products                  | 7.022639071 | 17      | 7.458034007    | 9       |
| Other non-metallic mineral products | 6.880040345 | 18      | 5.97226836     | 23      |
| Textiles                            | 6.602291836 | 19      | 5.229363677    | 25      |
| Rubber products                     | 6.212744352 | 20      | 5.399295643    | 24      |
| Other manufacturing products        | 5.895932472 | 21      | 6.204043301    | 20      |
| Glass and products                  | 5.803579219 | 22      | 6.009918041    | 22      |
| Wearing apparel, except footwear    | 5.515015898 | 23      | 3.865111854    | 27      |
| Fabricated metal products           | 5.513984278 | 24      | 6.108224644    | 21      |
| Total manufacturing                 | 5.035217269 | 25      | 7.183158099    | 12      |
| Printing and publishing             | 4.634205085 | 26      | 8.18032749     | 5       |
| Beverages                           | 4.122690753 | 27      | 6.238331092    | 19      |
| Other chemicals                     | 3.660652642 | 28      | 7.535671621    | 7       |
| Food products                       | 2.840748937 | 29      | 6.661717672    | 16      |

Table 6: USA: Aggregate quarterly data, GMM-estimation: Inflation &amp; TFP-growth

|                  | TFP-growth          |                       |                        |                        |                      |                        |                        |                        |
|------------------|---------------------|-----------------------|------------------------|------------------------|----------------------|------------------------|------------------------|------------------------|
|                  | OLS                 | GMM                   | GMM                    | GMM                    | GMM:60-75            | GMM:76-06              | GMM                    | GMM                    |
| inflation        | -.0030**<br>(-2.42) | -.0038***<br>(-2.59)  | -.0045***<br>(-2.95)   | -.0035**<br>(-2.52)    | -.0084**<br>(-2.31)  | -.0020<br>(-.71)       |                        |                        |
| yield-corp-bonds |                     |                       |                        |                        |                      |                        | -.0010**<br>(-2.21)    | -.0008<br>(-1.40)      |
| rgdp             | -1.1E-06<br>(-.98)  | -2.5E-06**<br>(-2.41) | -1.8E-05***<br>(-3.86) | -1.4E-05***<br>(-2.96) | -2.9E-05*<br>(-1.78) | -2.4E-05***<br>(-3.61) | -2.4E-05***<br>(-4.62) | -2.1E-05***<br>(-2.92) |
| gov-share        | -.0695<br>(-.42)    | -.2589*<br>(-1.74)    | .1780<br>(.71)         | -.0502<br>(.18)        | .5558<br>(.60)       | -.8126<br>(-1.36)      | .4684*<br>(1.84)       | .3702<br>(1.31)        |
| credit           | .0057<br>(.95)      | .0122**<br>(2.02)     | .0478***<br>(3.68)     | .0384***<br>(2.93)     | -.0275<br>(-.43)     | .0559***<br>(3.55)     | .0549***<br>(4.01)     | .0488***<br>(3.22)     |
| fin              | .0260*<br>(1.86)    | .0359**<br>(2.40)     | .0004<br>(.02)         | .0008<br>(.04)         | .3266*<br>(1.60)     | .0461<br>(1.35)        | -.0109<br>(-.49)       | -.0053<br>(-.27)       |
| time-trend       |                     |                       | .0005***<br>(3.40)     | .0004**<br>(2.47)      | .0015**<br>(1.98)    | .0008***<br>(3.03)     | .0008***<br>(4.54)     | .0007***<br>(2.62)     |
| inv-share        |                     |                       |                        | -.0448<br>(-1.09)      |                      |                        |                        | -.0145<br>(-.23)       |
| lag-dep.-var.    | -.1448*<br>(-1.73)  | -.1547*<br>(-1.89)    | -.1376<br>(-1.58)      | -.1346<br>(-1.56)      | -.2139**<br>(-2.03)  | -.1252<br>(-.93)       | -.0779<br>(-.94)       | -.0745<br>(-.88)       |
| Observations     | 158                 | 158                   | 158                    | 158                    | 46                   | 112                    | 158                    | 158                    |
| 1. serial-cor.   | .631                | -                     | -                      | -                      | -                    | -                      | -                      | -                      |
| 2. serial-cor.   | .591                | -                     | -                      | -                      | -                    | -                      | -                      | -                      |
| Hansen-test      | -                   | .760                  | .610                   | .437                   | .876                 | .101                   | .733                   | .540                   |

Always include institutional controls and a constant. Estimates reported for all control variables. 1960-1 - 2001-4 quarterly data. Endogenous variables: inflation, real GDP per capita in PPP, private & government shares, amount of overall credit, financial deposits. IVs: 1. & 2. lag of end. var. heteroscedasticity-robust s.e. t-statistics in parenthesis.

\*\*\*, \*\*, \* significant at 1%, 5%, 10%. Test statistics are reported in p-values. Null-hypothesis of well-specified model.

Table 7: USA: Aggregate yearly data, GMM-estimation: Inflation &amp; TFP-growth

|                  | TFP-growth          |                      |                      |                      |                      |                      |                      |                      |
|------------------|---------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|----------------------|
|                  | OLS                 | GMM                  | GMM                  | GMM                  | GMM:60-75            | GMM:76-02            | GMM                  | GMM                  |
| inflation        | -.3459**<br>(-5.85) | -.3876***<br>(-6.38) | -.4026***<br>(-4.90) | -.4182***<br>(-8.33) | -.3013**<br>(-2.20)  | -.3049***<br>(-4.92) |                      |                      |
| yield-corp-bonds |                     |                      |                      |                      |                      |                      | -.2643***<br>(-2.70) | -.4252***<br>(-4.54) |
| rgdp             | -4.3E-05<br>(-.15)  | -.0005*<br>(-1.80)   | -.0006*<br>(-1.80)   | -.0001<br>(-.34)     | .0004<br>(.40)       | -.0009**<br>(-2.57)  | .0001*<br>(.22)      | .0009**<br>(2.38)    |
| gov-share        | -63.83*<br>(-1.77)  | -78.70*<br>(-1.80)   | -92.94<br>(-1.58)    | -32.05<br>(-.84)     | -547.3***<br>(-4.34) | -199.2***<br>(-2.91) | 5.18<br>(1.84)       | 39.63<br>(1.01)      |
| credit           | -2.05<br>(-.95)     | .4302<br>(.24)       | .6178<br>(.35)       | -1.46<br>(-.86)      | -48.91***<br>(-5.19) | 2.22<br>(1.14)       | -.6108<br>(-.26)     | -5.52**<br>(-2.31)   |
| fin              | -3.85<br>(-.90)     | -.5699<br>(-.15)     | -1.78<br>(-.36)      | -1.717<br>(-.05)     |                      |                      | 4.72<br>(.89)        | 4.42<br>(.96)        |
| time-trend       |                     |                      | .0045**<br>(2.33)    |                      |                      |                      |                      |                      |
| inv-share        |                     |                      |                      | 31.11**<br>(2.27)    |                      |                      |                      | 50.75***<br>(2.81)   |
| lag-dep.-var.    | .0041*<br>(.03)     | -.0660<br>(-.62)     | -.0190<br>(-.13)     | -.2343**<br>(-2.23)  | -.2000**<br>(-2.03)  | .0193<br>(.15)       | .0614<br>(.45)       | -.2531*<br>(-1.77)   |
| Observations     | 41                  | 39                   | 39                   | 39                   | 13                   | 26                   | 41                   | 41                   |
| 1. serial-cor.   | .150                | -                    | -                    | -                    | -                    | -                    | -                    | -                    |
| 2. serial-cor.   | .295                | -                    | -                    | -                    | -                    | -                    | -                    | -                    |
| Hansen-test      | -                   | .376                 | .754                 | .912                 | .420                 | .322                 | .077                 | .089                 |

Always include institutional controls and a constant. Estimates reported for all control variables. 1960 - 2002 quarterly data. Endogenous variables: inflation, real GDP per capita in PPP, private & government shares, amount of overall credit, financial deposits. IVs: 1. & 2. lag of end. var. heteroscedasticity-robust s.e. t-statistics in parenthesis.

\*\*\*, \*\*, \* significant at 1%, 5%, 10%. Test statistics are reported in p-values. Null-hypothesis of well-specified model.

Apart from the first three specifications, we include the time-trend if significant.

Table 8: US sectoral yearly data:  
Inflation-sensitivity in volatile, high-growth and non-volatile, low-growth sectors

|               | Growth rate of value added |                     |                     |                      |                     |                     |                     |                     |
|---------------|----------------------------|---------------------|---------------------|----------------------|---------------------|---------------------|---------------------|---------------------|
|               | vol>med                    | vol<med             | vol>1.qua           | vol<3.qua            | av>med              | av<med              | av>1.qua            | av<3.qua            |
| inflation     | -1.61***<br>(-4.68)        | -1.18***<br>(-4.61) | -2.29***<br>(-6.49) | -.5552*<br>(-1.83)   | -1.70***<br>(-5.13) | -1.08***<br>(-4.21) | -1.16**<br>(-2.50)  | -1.26***<br>(-3.62) |
| trade         | 4.24***<br>(4.23)          | 2.10***<br>(4.13)   | 6.85***<br>(4.26)   | 1.73***<br>(3.07)    | 3.53***<br>(4.04)   | 2.75***<br>(3.85)   | 3.61***<br>(2.42)   | 2.69**<br>(2.52)    |
| credit        | 15.41<br>(1.06)            | -6.00<br>(-1.04)    | 41.66*<br>(1.71)    | -11.89***<br>(-3.41) | -3.71<br>(-.30)     | 12.11<br>(1.37)     | 1.26<br>(.07)       | 8.99<br>(0.71)      |
| fin           | 86.46***<br>(6.70)         | 16.60<br>(1.60)     | 118.1***<br>(5.00)  | 29.61***<br>(5.08)   | 61.94***<br>(3.18)  | 40.15***<br>(2.73)  | 65.54*<br>(1.90)    | 42.21*<br>(1.66)    |
| gov-share     | 2.95***<br>(-3.43)         | -2.15***<br>(-3.51) | -2.93**<br>(-2.26)  | -.6305<br>(-.99)     | -3.38***<br>(-4.63) | -1.78**<br>(-2.52)  | -1.81*<br>(-1.80)   | -2.32**<br>(-1.96)  |
| tot           | .0001***<br>(2.88)         | .0001***<br>(2.84)  | .0001***<br>(2.68)  | .0001*<br>(1.90)     | .0001***<br>(2.74)  | .0001**<br>(2.43)   | .0001<br>(.99)      | .0001<br>(1.35)     |
| lag-dep.-var. | -.0975**<br>(-2.45)        | -.0298<br>(-.57)    | -.1453**<br>(-2.20) | -.0276<br>(-.46)     | -.0710*<br>(-1.90)  | -.0786**<br>(-2.41) | -.1255**<br>(-2.50) | -.0713*<br>(-1.71)  |
| Per./Obs.     | 14/433                     | 14/433              | 7/217               | 7/216                | 14/432              | 14/434              | 7/216               | 7/217               |
| 1. auto-cor.  | .006                       | .001                | .032                | .019                 | .019                | .003                | .095                | .034                |
| 2. auto-cor.  | .610                       | .253                | .878                | .250                 | .868                | .097                | .454                | .389                |
| Sargan-test   | -                          | -                   | -                   | -                    | -                   | -                   | -                   | -                   |

Estimates reported for all variables. 1975-2000 yearly data. Always include a constant. Heteroscedasticity robust s.e. t-statistics in parenthesis. \*\*\*, \*\*, \* significant at 1%, 5%, 10%. We always employ the GMM-difference estimator. Endogenous variables: infl, trade, credit, fin.

Table 9: US firm-level quarterly data: Inflation, liquidity-holdings &amp; R&amp;D expenses

|                  | Corporate liquidity |                     | R&D expenses per firm |                       |                      |                       |                      |
|------------------|---------------------|---------------------|-----------------------|-----------------------|----------------------|-----------------------|----------------------|
|                  | GMM-sys             | GMM-sys             | GMM-sys               | GMM-sys <sup>1)</sup> | GMM-sys              | GMM-sys <sup>1)</sup> | GMM-sys              |
| inflation        | -1.06<br>(-1.10)    |                     | -.8556**<br>(-2.08)   | -.4257<br>(-1.01)     |                      |                       | -11.74***<br>(-2.81) |
| yield-corp-bonds |                     | -1.38**<br>(-2.20)  |                       |                       | -.5967***<br>(-2.77) | -.3137<br>(-1.51)     |                      |
| corp. liquidity  |                     |                     |                       | .0383***<br>(2.73)    |                      | .0382***<br>(2.73)    |                      |
| assets           | .0138***<br>(3.62)  | .0138***<br>(3.62)  | .0129***<br>(8.89)    | .0091***<br>(5.01)    | .0129***<br>(8.90)   | .0091***<br>(5.01)    | .0015***<br>(6.06)   |
| spdrc            |                     |                     |                       |                       |                      |                       | -1.65<br>(-.79)      |
| lag-dep.-var.    | .9013***<br>(14.77) | .9012***<br>(14.75) | -.0576<br>(-1.39)     | -.0783<br>(-1.02)     | -.0578<br>(-1.39)    | -.0785<br>(-1.02)     | -.0728**<br>(-1.94)  |
| Firms            | 5892                | 5892                | 6052                  | 6052                  | 6052                 | 6052                  | 425                  |
| Observations     | 115811              | 115811              | 121106                | 120730                | 121106               | 120730                | 7482                 |
| 1. auto-cor.     | .998                | .008                | .012                  | .018                  | .012                 | .018                  | .007                 |
| 2. auto-cor.     | .110                | .110                | .211                  | .140                  | .111                 | .140                  | .162                 |
| Hansen-test      | .464                | .480                | .125                  | .246                  | .113                 | .239                  | .697                 |

1) The IV-matrix starts at the 4. lag since Hansen-test indicates that 2. and 3. lag endogenous.

Table 10: US firm-level yearly data: Inflation, liquidity holdings and R&amp;D expenses

|                  | Corporate liquidity |                    | R&D expenses per firm |                    |                  |                       | <i>spdrc</i> < 12  | <i>spdrc</i> ≥ 12    |
|------------------|---------------------|--------------------|-----------------------|--------------------|------------------|-----------------------|--------------------|----------------------|
|                  | GMM-sys             | GMM-sys            | GMM-dif               | GMM-dif            | GMM-sys          | GMM-sys <sup>1)</sup> | GMM-sys            | GMM-sys              |
| inflation        | -1.330**<br>(-2.26) |                    | -.4514*<br>(-1.65)    | -.3555<br>(-1.59)  |                  |                       | -3.721*<br>(-1.72) | -22.514**<br>(-2.16) |
| yield-corp-bonds |                     | -1.61**<br>(-2.34) |                       |                    | -.0366<br>(-.34) | .0889<br>(.88)        |                    |                      |
| corp. liquidity  |                     |                    |                       | .0353***<br>(4.27) |                  | .0486***<br>(4.20)    |                    |                      |
| assets           | .0231**<br>(2.25)   | .0231**<br>(2.25)  | .0034**<br>(2.20)     | .0020<br>(1.50)    | .0007<br>(-1.19) | -.0010<br>(-1.57)     | -.0014<br>(-.74)   | -.0008<br>(-.24)     |
| spdrc            |                     |                    |                       |                    |                  |                       | -99.1<br>(-1.24)   | -439.3**<br>(-2.09)  |
| lag-dep.-var.    | .7356***<br>(7.77)  | .7357***<br>(7.77) | .8530<br>(19.64)      | .8237<br>(17.73)   | 1.01<br>(29.43)  | .9462<br>(21.00)      | .100<br>(14.69)    | .9289<br>(7.52)      |
| Firms            | 10923               | 10923              | 9744                  | 10925              | 9742             | 10925                 | 378                | 492                  |
| Observations     | 84277               | 84277              | 72787                 | 72759              | 84355            | 84314                 | 6217               | 5194                 |
| 1. auto-cor.     | .002                | .002               | .001                  | .002               | .001             | .001                  | .017               | .182                 |
| 2. auto-cor.     | .487                | .488               | .605                  | .536               | .616             | .533                  | .519               | .474                 |
| Hansen-test      | .259                | .260               | -                     | -                  | .075             | .267                  | 221                | .274                 |

1) The IV-matrix starts at the 4. lag since Hansen-test indicates that 2. and 3. lag endogenous.