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Inflation, liquidity risk, and long-run TFP-growth

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Abstract

This paper demonstrates a negative relation between inflation and long-run productivity growth. Inflation generates long-run real effects due to a link from the short-run nominal and financial frictions to a firm's qualitative investment portfolio. We develop an endogenous growth model whose key ingredients are (i) a nominal short-run portfolio choice for households, (ii) an agency problem which gives rise to financial market incompleteness, (iii) a firm-level technology choice between a return-dominated but secure and a more productive but risky project. In this framework, inflation increases the costs of corporate insurance against productive but risky projects and hence a firm's choice of technology. It follows that each level of inflation is associated with a different long-run balanced growth path for the economy as long as financial markets are incomplete. Finally, we apply U.S. industry and firm level data to examine the relevance of our specific microeconomic mechanism. We find that (i) firms insure systematically against risky R&D investments by means of corporate liquidity holdings, (ii) periods of higher inflation restrain firm-level R&D investments by reducing corporate liquidity holdings.

1 Introduction

Does inflation reduce long-run economic growth? If so, what is the key transmission mechanism relating inflation to long-run growth? To answer these questions, we provide empirical evidence - in accordance with Fischer (1993) and others - that the level of inflation reduces long-run productivity growth. Thereafter, we develop a novel theoretical explanation for a long-run relation between the two variables in the context of an endogenous growth model with financial market frictions. Our transmission mechanism relates the qualitative composition of investments, instead of their quantity, to the level of inflation. Hence, we partly endogenize total factor productivity (TFP) by demonstrating that monetary policy is a relevant component of long-run TFP-growth. Finally, we present micro-econometric evidence from disaggregated U.S. sectoral and firm-level data that is consistent with our specific microeconomic mechanism underlying the macroeconomic monetary transmission channel.

Recent progress in development accounting have identified differences in total factor productivity (TFP), rather than physical or human capital accumulation, as the main factor generating cross-country income and growth differences.[1] Accordingly, variations in TFP explain about

[1] Caselli (2005) provides an exhaustive survey of recent contributions to development accounting and demonstrates the robustness of this result.

2/3 of the variations in income across countries. However, TFP is measured as the component of output that is not explained by labor or (human) capital inputs. Therefore, Abramovitz (1956) refers to this residual measure as the "*measure of our ignorance*". Against this background, substantial efforts have been devoted to endogenize TFP.[2] The effect of nominal variables on real economic activities, on the other hand, has been mainly analyzed in a business cycle framework. In this respect, it is well recognized that monetary policy can influence fluctuations in real variables in the short-run, but most theoretical contributions treat monetary policy shocks and total factor productivity as orthogonal in the long-run. Accordingly, the determinants of growth and cycles are most often regarded as two separated entities.[3]

Our theoretical contribution takes a different route and combines elements of the growth and business cycle literature. Specifically, we analyze the interplay between short-run nominal and financial frictions and its effect on long-run endogenous technological change. The standard endogenous growth model is supplemented in three dimensions. *First*, we incorporate a technology choice for producers. That is, intermediate firms can channel investments into two distinct projects: a safe, but return-dominated ("basic") and a superior ("advanced") project which yields higher expected returns, but is subject to idiosyncratic liquidity shocks. We attribute investments that enhance the stock of technologies available for a firm, e.g. R&D expenses, to the advanced projects since this type of investment is considered to be more productive, but also more risky. Thus, (part of the) expenses for advanced technologies generate a positive externality on the future stock of knowledge/technologies available in the economy. In contrast, investments in the basic technology reflect, for example, expenses for machines of the same vintage relative to previous ones. Moreover, firms operating the advanced technology can insure themselves against the idiosyncratic liquidity risk by means of holding a precautionary stock of readily marketable assets; however, due to an entrepreneurial moral hazard problem, which is the *second* 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) - can not be efficiently provided to the productive sector. *Third*, we assume that households are required to hold cash in order to consume at the end of a period. This short-run cash-in-advance constraint implies that households have to choose between cash holdings for consumption purposes and deposits with a financial intermediary that earn a net interest rate. It follows that the short-run supply of nominal assets (liquidity) is costly even in an environment of flexible prices. Taken together with the positive short-run demand for liquidity of firms operating the advanced technology this approach involves a positive short-run nominal interest rate that represents the cost of insurance against liquidity shocks. That is, the nominal interest rate constitutes an additional cost of production by means of the advanced technology relative to the basic one. This complementarity between corporate liquidity holdings and a firm's ability to invest in productive but risky projects leads to a type of *inflation*

[2]The title of a contribution by Prescott (1998) anticipates recent developments in the endogenous growth literature: "Needed: A Theory of Total Factor Productivity". So far, the most prominent explanations for cross-country differences in TFP concentrate on the role of government regulations (Prescott, 1998), human capital (Benhabid and Spiegel, 2005), or institutions (Acemoglu and Robinson, 2002).

[3]This observation is well paraphrased by Aghion et al. (2005): *"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."*

tax on productivity-enhancing investments. The short-run non-neutrality of monetary policy induces an investment composition effect that is found to be associated with changes in the aggregate stock of technologies in the long-run. Hence, the model postulates a novel aspect of monetary transmission in that differences in the level of inflation across countries or time periods induce long-run differences in TFP-growth as long as financial markets are incomplete.

Our empirical macroeconomic evidence demonstrates the robustness of this negative empirical relation. We apply a dynamic panel technique following Blundell and Bond (1998) which allows some inspection of causality. Accordingly, we find that inflation reduces long-run TFP-growth, whereby its exogeneity can not be rejected. Furthermore, the firm-level moral hazard problem results in a constrained-efficient contracting scheme between firms and financial intermediaries. This endogenous form of financial market incompleteness allows for a set of empirical implications which are specific to our model. We test these implications using disaggregated U.S. sectoral and firm-level panel data. The results demonstrate that firms with riskier cash-flows and higher R&D investments systematically adjust the composition of their asset and investment portfolios in periods of higher inflation. In particular, we find that (i) the sensitivity of TFP-growth with respect to inflation is significantly higher in more volatile and more productive sectors, (ii) periods of higher inflation restrain firm-level R&D investments by reducing corporate liquidity holdings.

The rest of the paper is organized as follows. In section 2, we review the literature on inflation and long-run economic growth. Section 3 examines the aggregate empirical relation between inflation and long-run TFP-growth. The next two sections describe the theoretical model as the basic structure to highlight the novel monetary transmission mechanism. In section 6, we test model-specific implications applying sectoral and firm-level panel data in order to identify the underlying microeconomic mechanism empirically. A final section concludes.

2 Literature review

A limited number of theoretical studies allow for an impact of changes in nominal variables on long-run economic growth. In this regard, King et al. (1988) incorporate constant returns to capital in a real business cycle model showing that temporary nominal shocks can have permanent effects due to a reduction in capital investments. Similarly, Aizenman and Marion (1993) develop a negative relation between nominal fluctuations and GDP-growth due to the existence of investment irreversibility. More recently, Fatas (2001) relates long-run growth to short-run business cycles. He embeds an aggregate demand externality in an endogenous growth model to show that the coordination of productive investments across different sectors may be an important prerequisite for aggregate economic development. In contrast to our contribution, the permanent effects in the above models are transmitted via the aggregate quantity of investments, instead of their quality. However, Ramey and Ramey (1995) reveal that the negative empirical correlation between nominal macroeconomic fluctuations and the trend of GDP-growth is independent of the aggregate quantity of investments which contradicts the predictions of the above models.

Aghion et al. (2005) and Angeletos (2006) focus on the link between financial market incompleteness and business cycle fluctuations. The former examine how (exogenous) credit constraints affect the cyclical behavior of productivity-enhancing investment. Specifically, they distinguish between a short-term and a long-term investment project which enhances future productivity. 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. The authors show that sufficiently tight credit constraints result in a procyclicality of long-term investment which amplify 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. Their key result is that incomplete markets reduce TFP by shifting resources away from the more risky, but also more productive private equity investment. Both Aghion et al. (2006) and Angeletos (2007) are concerned with real general equilibrium economies; they do not address a potential interplay between nominal and financial frictions. Moreover, they focus on the impact of exogenous credit constraints on an economy's cyclical productivity dynamics and not on the evolution of the long-run trend. In order to better understand the determinants of the interaction between nominal and financial frictions, it is important to carefully specify the source of market incompleteness which gives rise to uninsured idiosyncratic risk. Therefore, we embed the financial contracting problem discussed in Holmstrom and Tirole (1998) in our model. This endogenous form of financial market incompleteness makes it possible to derive a number of theoretical predictions which can be examined empirically.

Acemoglu and Zilibotti (1997), among others, develop a theoretical link between the degree of financial market development and long-term growth. Their reasoning is based on the ability of agents to share the risk of investment projects. Thus, capital investments in poor economies are constraint by risk diversification opportunities. The model explains why the level and volatility of output are high in less developed countries and decline with the degree of financial market development. Moreover, Levine et al. (2000) provide empirical evidence in favor of a causal link from financial development to economic growth. However, in contrast to these approaches, we focus on the interplay between inflation and financial market frictions. That is, incomplete financial markets transmit short-run nominal constraints to long-run restrictions on the productivity trend in our model.

The empirical literature on inflation and growth employs cross-country (panel) regressions with low frequency data.[4] In this context, Bruno and Easterly (1998) and Easterly et al. (2005) suggest that the negative relation between GDP-growth and inflation is mainly due to *inflation outliers*. Assuming different threshold levels (e.g. 20%, 40%) they detect that the robustness of the negative relation depends on high-inflation countries. In contrast, Fischer (1993) finds that the negative correlation between inflation and TFP-growth is, if anything, larger in low-inflation (OECD-) countries. Moreover, Fischer investigates the causal mechanism behind this correlation in several ways. First, he examines the potential endogeneity of inflation by considering sample variations across periods predominated by demand (1960-1972) or supply (1973-1988) shocks.[5] In line with the established literature, he starts from the presumption that adverse supply shocks are the main source of the endogeneity of inflation, i.e. while an

[4] Important contributions in this branch of research include De Gregorio (1992, 1993) and Barro (1996).

[5] 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 in Section 3 circumvents the problem by applying dynamic panel regressions, thus relying on internal instruments whose validity is testable.

adverse supply shock is inflationary, an adverse demand shock would be deflationary. However, he finds that the correlation between inflation and economic growth remains unchanged across periods of mainly demand or supply shocks and therefore is led to the conclusion that inflation is exogenous with respect to growth. Second, the author decomposes GDP growth into its components and detects a robust negative relation between inflation the growth rate of TFP. Thus, even after controlling for factor accumulation and employment, the negative effect of inflation on growth persists. It follows that there must be some inflation-driven mechanism which records in terms of decreased aggregate productivity growth.

The structure of the model we develop suggests that the availability of corporate liquidity is a crucial determinant for firm-level qualitative 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 U.S. firms.[6] The authors establish that (i) firms with better outside financing opportunities tend to hold a lower fraction of their total assets in the form of liquid assets, and that (ii) firms with strong growth opportunities and riskier cash flows hold relatively high ratios of cash to total non-cash assets.[7] 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, i.e. the corporate liquidity is held as a hedge against production risk. 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 18%, while the median amounts to 6.5%. Thus, corporate liquidity holdings are likely to constitute a quantitatively relevant expense factor in the presence of inflation.

3 Inflation- TFP-growth nexus

Data and methodology: In this section, we complement the work of Fisher (1993) in that we apply a different econometric method and supplementary robustness tests to investigate the inflation TFP-growth nexus. The aggregate empirical analysis is based on an unbalanced panel data set consisting of 88 countries from 1970-1999. We employ non-overlapping 5-year averages to smooth out business cycle effects which reduces the time dimension to six observations per country.[8] Inflation is measured by the first difference of the natural logarithm of the real consumer price index from the World Development Indicator database (WDI). In addition, we include various institutional and financial control variables to minimize the potential of an omitted variable bias. In particular, we approximate a country's degree of financial market development by the amount of private credits relative to GDP (*credit*).[9] Furthermore, we account

[6] 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.

[7] We interpret these latter features - high growth potential and risky cash flows - as the identifying characteristics of what we label "advanced" technology.

[8] Specifically, we use the following time averages: 1970-1974, 1075-1979, ..., 1995-1999.

[9] The proxy is obtained from from Beck and Levine (2000). We note that all of our results are robust to the inclusion of alternative proxies from these authors such as the amount of liquid liabilities, the rate of stock

for the following control variables: the government and private investment shares from the Penn World Tables, the amount of trade in goods as % of GDP (WDI), the terms of trade (WDI), an index of overall property rights from the Fraser Institute of Economic Freedom database, and a measure of inflation uncertainty. We construct the TFP series following Caselli (2006). A detailed description of the growth accounting methodology is provided in the appendix A.5. In line with the empirical growth literature, we include the lagged level of TFP as a lagged dependent variable in the growth regression.[10] Accordingly, we apply a dynamic panel data model. Therefore, we employ the method developed by Blundell and Bond (1998) which is based on the general method of moments (GMM) and is constructed to yield consistent estimates in dynamic panels.[11] This procedure instruments predetermined and endogenous variables with the suitable corresponding lags of these variables. It allows to gain inspection of causality and provides a tests of autocorrelation and overidentifying restrictions to check for the validity of the instruments.

Results: In Table 2, we investigate the reduced-form relation between the two aggregate series controlling for spurious correlation and endogeneity of inflation. The first column reports a negative contemporaneous correlation between inflation and TFP-growth after controlling for the institutional and financial indicators. Correspondingly, this negative correlation does not simply capture an economy's degree of financial or institutional development. In the next column, we apply the least square dummy variable estimator to additionally control for country fixed effects. The coefficient of inflation is still significant on a 1% level. Yet, the corresponding estimates are biased in the presence of a lagged dependent variable. Therefore, we present our preferred specification based on the method of Blundell and Bond (1998) in column three. Accordingly, inflation, which is instrumented by its suitable own lags, reduces TFP-growth. The corresponding coefficient is significant on a 1% level.[12] Thus, our results suggest that causation is running from inflation to TFP-growth. Moreover, TFP-growth is decreasing in the lagged level of TFP and increasing in the measure of overall property rights. The Hansen test

market trade, or the amount of financial deposits. The results are available from the authors upon request.

[10]The corresponding coefficient is negative and significant on a 1% level in all estimation specifications. Compare e.g. Calderón and Servén (2005) or Barro and Sala-i-Martin (1995), and Aghion et al. (2006) for analogous approaches.

[11]In other words, considering the following dynamic panel data model in first differences:

$$y_{i,t} - y_{i,t-1} = \alpha(y_{i,t-1} - y_{i,t-2}) + \beta(X_{i,t} - X_{i,t-1}) + (\epsilon_{i,t} - \epsilon_{i,t-1}), \quad i = 1, 2, ..., N, t = 3, 4, ..., T,$$

the basic assumptions of Arellano and Bond (1991) are $E[y_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0$, $E[X_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0$ for $s \geq 2; t = 3, ...T$, where $y_{i,t}$ is the dependent variable, $X_{i,t}$ a vector of endogenous and exogenous explanatory variables, N the number of cross-sections, T the number of time-periods, $\epsilon_{i,t}$ the error term and α and β parameters to be estimated. In addition, Blundell and Bond (1998) apply supplementary moment restrictions on the original model in levels, whereby lagged differences are used as additional instruments for the endogenous and predetermined variables in levels. Given that $E[y_{i,t}, \mu_i]$ is mean stationary, the Blundell and Bond (1998) estimator incorporates the additional moment restrictions $E[(y_{i,t-1} - y_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0$, $E[(X_{i,t-1} - X_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0$, which requires the additional assumption of no correlation between the differences of these variables and the country-specific effect. The authors show that this procedure is more efficient if explanatory variables are persistent.

[12]We stress that the average effect of a 1% point increase is relatively small since some countries experienced excessive inflation rates. In particular, inflation varies from 0-6000% while TFP-growth varies from -10-10% in our sample. This reduces the average marginal effect of a 1% point increase substantially. We outline below that the average marginal effects are much larger if we focus on the OECD sub-sample or U.S. time series data.

and the test of second order autocorrelation signalize that the validity of the instruments can not be rejected.

In the remaining columns of Table 2, we conduct several robustness checks for our basic specification. Column four reveals that an increase in the private investment share enhances TFP-growth. However, the corresponding coefficient of inflation is still significant on a 5% level even after controlling for the fluctuations in aggregate investments. We infer that the transmission channel of inflation is independent from private factor accumulation. This result affirms our conjecture that inflation affects the quality (composition) of private investments instead of their quantity.[13] Column five shows that our results are robust to the inclusion of time fixed effects which control for aggregate shocks that are common for all countries in each time period. In column six and seven, we try to discriminate empirically between level and uncertainty effects of inflation. Therefore, we incorporate the standard deviation of inflation as a proxy for inflation uncertainty.[14] The standard deviation significantly reduces TFP-growth if we abstract from level effects. Yet, we exclusively find a significant negative effect of the level of inflation if we account for both uncertainty and level effects. However, we note that the level and the standard deviation of inflation are highly correlated in our sample. Nevertheless, these results suggest that the distorting impact of inflation is due to movements in the level of inflation instead of changes in inflation uncertainty. Finally, the last column of Table 2 displays the results for the sub-sample of 22 OECD countries. Accordingly, a 5% increase in inflation reduces TFP-growth in this sub-set of developed economies, on average, by .35% in the same time period.[15] The negative coefficient is significant on a 1% level. The coefficient in the OECD sub-set is more pronounced since many countries suffered from periods of excessive inflation which reduces the marginal effect of a 1% point increase in inflation if we consider the full sample. This result supports the hypothesis that inflation reduces TFP-growth even in regions/periods of moderate or low inflation. Summing up, the aggregate results highlight a negative empirical relation between inflation and TFP-growth in the data with causality running from the former to the latter.

4 The model

In this section, we introduce an endogenous growth model which accounts for short-run nominal and financial frictions to illuminate the long-run negative causation running from inflation to TFP-growth. The economy is populated by two sets of agents, households and entrepreneurs, each of unit mass. Moreover, there are a financial intermediation and a productive sector. The latter is organized in decentralized firms, which have access to two distinct technologies: a "basic" technology which is return-dominated but risk-free and a more productive but risky "advanced" technology.[16] There exist various interpretations of what the two types of invest-

[13] This result is in line with the earlier findings of Ramey and Ramey (1995) and Aghion et al. (2005) on (nominal) volatility and GDP-growth.

[14] Uncertainty is measured as the average annual standard deviation for a corresponding 5-year-interval.

[15] A 1% increase in inflation reduces the average annual U.S. TFP-growth by .4% if we exclusively focus on yearly U.S. time series data from 1975-2000. In this case, we employ the first two lags of inflation as instruments for the contemporaneous levels. The results are available from the authors upon request.

[16] 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.

ments represent. For example, the basic project might reflect investments in machines of the same vintage relative to previous ones, while the advanced project might represent investments in R&D, the learning a new skill, or the adoption of a new technology.[17] 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 government policy materializes and information about it is revealed, and finally one at the end of the period, denoted t^+. Monetary policy, which is perfectly observable before individual decisions are realized each period, is the only source of aggregate uncertainty since we focus on the inflation-growth nexus. Apart, there exist purely idiosyncratic liquidity shocks ξ_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 long-run balanced growth path of the economy.

4.1 Households

The economy is populated by a unit mass of infinitely-lived, risk averse households.[18] Households enter a given period t 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 $(\tilde{R}_t - 1)$.[19] Thus, there is a cash constraint on the goods market with the consequence that the household's current expenditure for consumption c_t^H must be covered by the resources Q_t. After aggregate shocks have unfolded, households rent out their sector-specific physical capital to the firms which operate a portfolio of projects using the basic and advanced technology, respectively. Moreover, they supply their labor inelastically. That is, each household is endowed with a constant amount of labor which can be used for either of the two intermediate sectors, whereby households are indifferent as to the sectoral composition of their labor supply. Hence, the constant aggregate supply of household labor amounts to: $\overline{h}^H = h_t^H = h_t^{k,H} + h_t^{z,H}$. Households are indifferent as to where their labor is employed. As an equilibrium consequence, the sectoral wage rates must be identical, ie. $W_t^{k,H} = W_t^{z,H} = W_t^H$. At time t^+, households receive the returns from labor $(W_t^{k,z})$ and capital $(R_t^{k,z})$ and make their consumption decisions. The household has preferences over sequences of consumption; hence, the household problem is to maximize lifetime utility:

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

subject to the cash constraint:

$$Q_t \geq P_t \left[c_t^H + x_t \right], \tag{1b}$$

and an equation describing the evolution of nominal assets:

[17] Similarly, the basic project might be putting money into the current business, while the advanced reflects the start-up of a new business. See Aghion et al. (2005) for further discussion.

[18] Where necessary, variables pertaining to the household sector will be denoted with a superscript H.

[19] This timing convention is standard in monetary models which feature a cash-in-advance constraint 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^+).

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

where $\mathcal{J}_t$ are cash injections into the financial market on behalf of the government and Υ_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 physical capital $x_t = k_t + z_t$, which accounts for depreciation:

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

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 inter-temporal allocation of nominal wealth:

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

Equation (2) implies a type of Fisher relation in that the nominal interest rate is a function of the rate of inflation and the real interest rate in equilibrium. The latter is in turn governed by the balanced growth rate of consumption and parameters of the utility function. Next, there are two Euler equations which determine the sequence of dynamic decisions between consumption and sector-specific investments; for $i = k, z$:

$$u_c(c_t^H) = \beta E_t\left\{u_c(c_{t+1}^H)\left[(1-\delta) + \frac{r_{t+1}^i}{\tilde{R}_{t+1}}\right]\right\}, \quad (3)$$

where $r_{t+1}^i = \frac{R_{t+1}^i}{P_{t+1}}$ is the real rental rate of capital in sector i in period $(t+1)$. An immediate implication of the two equations (3) is that the sector-specific rental rates must be equal in expectation, i.e. $E_t\{r_{t+1}^k\} = E_t\{r_{t+1}^z\} = E_t\{r_{t+1}\}$.

4.2 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.[20] 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.[21] The remaining measure η 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

[20]Apart from the fact that investments in the advanced project might represent investments in human capital, we do not consider limitations in that production factor. Yet, a straightforward way to think about restrictions in the economy's endowment of human capital (in our model) is an endogenous mass of risk neutral entrepreneurs, which are capable of running the advanced project.

[21]Where necessary, variables pertaining to the entrepreneurial sector will be denoted with a superscript E.

$A_t^i = P_t c_t^{E,i}$. 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. Hence, an individual entrepreneur's effective wealth position is $E_t^i = A_t^i + W_t^E$. 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.

4.3 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 $\tilde{R}_t$. At the loan market, this supply meets the demand for nominal financial assets coming from the demand for liquidity D_t of firms operating the advanced technology. Hence, financial market clearing requires:

$$M_t - Q_t + \mathcal{J}_t = D_t \tag{4}$$

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 need for liquidity. The financial intermediary operates after monetary policy is resolved and lends liquidity to the advanced sector firms. Yet, the provision of funds to advanced projects is complicated by an entrepreneurial moral hazard problem which is dealt with by a financial contract described in Section 4.5. Two key implication 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. 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.

4.4 Firms

In our economy, production activities proceed in two different steps. First, investments in basic and advanced technologies results in two different types of intermediate goods (y_t^k, y_t^z). Second, the two types of intermediates are combined to produce the final market good (y_t) that is used for consumption purposes. In all three goods markets, firms face perfect competition.

4.4.1 Market good

The market good producers employ the following CES aggregation technology:

$$y_t = \left(\zeta^{\frac{1}{\rho}} {y_t^k}^{\frac{\rho-1}{\rho}} + (1-\zeta)^{\frac{1}{\rho}} {y_t^z}^{\frac{\rho-1}{\rho}}\right)^{\frac{\rho}{\rho-1}}, \tag{5}$$

where 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:

$$y_t^k = \zeta \left(\frac{P_t^k}{P_t} \right)^{-\rho} y_t \qquad \text{and} \qquad y_t^z = (1-\zeta) \left(\frac{P_t^z}{P_t} \right)^{-\rho} y_t \tag{6}$$

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:

$$P_t = \left(\zeta {P_t^k}^{1-\rho} + (1-\zeta) {P_t^z}^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{7}$$

4.4.2 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 4.5. The need for this insurance arises as a consequence of an entrepreneurial moral hazard problem which prevents the efficient refinancing of advanced projects and calls for the commitment of liquidity at an ex ante, rather than an ex post stage. A natural way to think about advanced technology projects are investments in R&D or the adoption of new (foreign) technologies. We assume, in accordance with the literature on endogenous growth, that investments in the advanced technology involve spill-overs to the future stock of knowledge ($\mathcal{T}_t$).[22] Consequently, aggregate productivity has two components: an exogenous and an endogenous one. The exogenous productivity parameters differ in both sectors, whereby the productivity of the advanced technology is strictly larger than the basic one by definition ($\mathcal{V} > \mathcal{A}$). We abstract from variations in the exogenous productivity parameters over time since we focus on the growth-effect of short-run nominal fluctuations instead of technology-induced cycles. In addition to the exogenous components of productivity, there is an endogenous one. The endogenous component $\mathcal{T}_t$, which we call the level of knowledge, augments the productivity of both projects; the determination of $\mathcal{T}_t$ will be described later. Note that the advanced sector is characterized by perfect competition. Hence, investments in R&D take place not because of a monopolistic market structure, but due to the incentives for firms to optimize the composition of their investments. That is, the risk associated with R&D investments combined with the financial market incompleteness limit the capacity of R&D ex ante. Consequently, as opposed to the endogenous growth literature à la Romer (1990) or Aghion and Howitt (1992), the key feature of R&D is not the creation of

[22] Compare Romer (1990) or Aghion and Howitt (1992). It does not matter in our framework if the spill-overs reflect actual investments in R&D or the scope of the advanced technology for accidental learning-by-doing.

monopoly rents, but its superior productivity combined with the risk associated to it.

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:

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

The technology characterizing the basic intermediate sector is assumed to be homogenous of degree one. For simplicity, we employ the Cobb-Douglas form:

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

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

$$\begin{aligned} \max_{\{k_t, l_t^k\}} \Pi_t^k &= P_t^k\left(\mathcal{T}_t\mathcal{A}\varphi(k_t, l_t^k)\right) - W_t^k l_t^k - R_t^k k_t \\ &= P_t^k y_t^k - C(W_t^k, R_t^k; y_t^k) \end{aligned} \tag{8}$$

By constant returns to scale, efficient factor employment implies that marginal costs are independent of the quantity produced, i.e. $C(W_t^k, R_t^k; y_t^k) = MC_t^k(W_t^k, R_t^k; 1)y_t^k$. 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. $P_t^k = MC_t^k(W_t^k, R_t^k)$. Using the Cobb-Douglas specification of $\varphi(k_t, l_t^k)$, the optimal factor demands in the basic sector read:

$$k_t = \frac{\alpha P_t^k y_t^k}{R_t^k} \qquad \text{and} \qquad l_t^k = \frac{(1-\alpha)P_t^k y_t^k}{W_t^k} \tag{9}$$

Finally, the price for the basic intermediate good is:

$$P_t^k = \frac{1}{\mathcal{T}_t\mathcal{A}}\left(\frac{R_t^k}{\alpha}\right)^{\alpha}\left(\frac{W_t^k}{(1-\alpha)}\right)^{(1-\alpha)} \tag{10}$$

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[23] which may trigger the

[23] The liquidity shock admits a variety of interpretations. It can be thought of a simple cost overrun, as a shortfall of revenue at an interim stage which could have been used as an internal source of refinancing, as adverse information relating to the project's end-of-period profitability, an extra cost to familiarize the workers with the new technologies, or as an extra costs necessary for the new technology to be adapted to domestic market conditions once the new technology has been adopted. 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.

termination of productive projects before they yield any return. We assume that all advanced projects feature an ex post positive net present value if the entrepreneur has exerted effort. 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 also given by a Cobb-Douglas production function under constant returns to scale:

$$\phi(z_t, l_t^z) = (z_t)^{\alpha} \left(l_t^z\right)^{1-\alpha}$$

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 ξ_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 4.5, turns out to be linear in E_t^i, the distribution of equity across entrepreneurs does not matter and exact aggregation is possible.[24] 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:

$$P_t^z = \frac{1}{\tilde{R}_t \int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t} \frac{1}{\mathcal{T}_t \mathcal{V}} \left(\frac{R_t^z}{\alpha}\right)^{\alpha} \left(\frac{W_t^z}{(1-\alpha)}\right)^{(1-\alpha)} \tag{11}$$

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

4.5 Financial contracting

Following Holmstrom and Tirole (1998), we now turn to a detailed analysis of the contracting problem which is specific to the advanced technology. In principle, all investment projects might face constraint financing opportunities. In this respect, the exact identifying assumption in our model is that the riskiness of an investment project is, on average, increasing in its productivity. However, we separate the technology choices into two classes according to their productiveness whereas the riskiness of less productive projects is normalized to zero to simplify the analysis of our model. The sequencing of events underlying an individual advanced firm's within-period contracting problem can be decomposed into three stages.[25]

At *stage one*, after information about monetary policy ($\mathcal{J}_t$) 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.[26] In particular, the refinancing provisions determine the degree of insurance against idiosyncratic liquidity

[24]From now on, we will therefore drop the superscript i.

[25]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 inter-temporal incentive provision.

[26]We assume that entrepreneurial self-financing is not possible; a sufficient condition for this to be the case is derived in the appendix.

risk.[27] Thereafter, 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 ξ_t. If the shock is met by appropriate refinancing to be provided by the intermediary, the firm can continue; otherwise the firm is liquidated.[28] 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 define that, conditional on continuation, exerting effort guarantees a gross return of $P_t^z \mathcal{T}_t \mathcal{V} f(z_t, l_t^z) = P_t^z \tilde{y}_t^z$ 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: $B_t = bP_t^z \mathcal{T}_t \mathcal{V} f(z_t, l_t^z) = bP_t^z \tilde{y}_t^z$ with $0 < b < 1$.[29] 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 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 one 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.

[27] 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.

[28] 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.

[29] 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.

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 $C\left(W_t^z, R_t^z; \tilde{y}_t^z\right)$, respectively, then solves the following second best program of maximizing the entrepreneur's net return:

$$\max_{\mathcal{C}_t} \int \left\{\Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C\left(W_t^z, R_t^z; \tilde{y}_t^z\right)\right\} dG(\xi_t) - E_t \tag{12a}$$

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

$$\int \left\{\tau_t(\xi_t) C\left(W_t^z, R_t^z; \tilde{y}_t^z\right) - \Gamma_t(\xi_t)\xi_t \tilde{R}_t P_t^z \tilde{y}_t^z\right\} dG(\xi_t) \geq C\left(W_t^z, R_t^z; \tilde{y}_t^z\right) - E_t \tag{12b}$$

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

$$\Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C\left(W_t^z, R_t^z; \tilde{y}_t^z\right) \geq \Gamma_t(\xi_t) b P_t^z \tilde{y}_t^z \qquad \forall\, \xi_t, \tag{12c}$$

where:

$$\tilde{y}_t^z = \mathcal{T}_t \mathcal{V} \left(z_t\right)^{\alpha} \left(l_t^z\right)^{1-\alpha}$$

is firm level output conditional on survival and:

$$C\left(W_t^z, R_t^z; \tilde{y}_t^z\right) = W_t^z l_t^z + R_t^z z_t$$

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 (12b), 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 (12).

The algebraic solution to the optimal contract defined in (12) is provided in the appendix A.1. Intuitively, the constraint optimal contract implies that the firm is the residual claimer of the return of investment given that the outside investor breaks even in expectations. Thus, the firm wants to maximize the initial scale of investment. If we define $\hat{\xi}_t^0 = \frac{1-b}{\tilde{R}_t}$ as the cutoff value that maximizes the expected marginal return to outside investors, it follows that the optimal cutoff value, which defines the equilibrium provision of liquidity at the interim stage, must be in the interval $\hat{\xi}_t^* \in [\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$. That is, if $\xi_t < \hat{\xi}_t^0$, then both parties prefer to continue ex post because both parties can realize gains on the investment in the sunk stage one; 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 $MC_t^z(\cdot)\tilde{y}_t^z$.

The solution of the constraint efficient contract results in an the optimal continuation value $\hat{\xi}_t^*$ that satisfies the optimality condition:

$$\int_0^{\hat{\xi}_t^*} G(\xi_t)d\xi_t = \frac{MC_t^z(\cdot)}{P_t^z}\frac{1}{\tilde{R}_t} \tag{13}$$

This condition reflects that the maximum equilibrium provision of liquidity must coincide with the adjusted markup on advanced sector output prices, whereas the adjustment represents the cost of providing liquidity which is given by the nominal interest rate $(\tilde{R}_t)$.

Hence, second best contracting is indeed consistent with liquidity holdings at the firm level, whereby the nominal interest rate $\tilde{R}_t$ reflects the shadow price for such scarce liquidity. Moreover, we can derive a measures of aggregate liquidity demand under financial intermediation by aggregating over the advanced sector firms:

$$D_t^* = \left[\int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t)d\xi_t\right] P_t^z\tilde{y}_t^z < \bar{D}_t \tag{14}$$

Thus, the second best liquidity demand under financial intermediation, which efficiently economizes on the use of scarce liquidity by pooling liquidity risk across firms, falls below the demand that results from a policy which disregards the scope for risk sharing across firms.

4.6 Empirical implications

As an immediate consequence of optimal financial contracting as derived in Section 4.5 and A.1, we put on record the following empirical implications of optimal financial contracting as governed by equation (13), which will be subject of our later empirical analysis of industry and firm-level panel data.

- $\mathcal{H}1$: *Ceteris paribus*[30], an increase in $\tilde{R}_t$ leads to a lower cutoff $\hat{\xi}_t^*$:

$$\frac{d\hat{\xi}_t^*}{d\tilde{R}_t} = -\frac{\int_0^{\hat{\xi}_t^*} G(\xi_t)d\xi_t}{\tilde{R}_t G(\hat{\xi}_t^*)} < 0, \tag{15}$$

  which follows from total differentiation of condition (13).

[30] 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. However, to obtain a closed-form solution, we have to determine a functional form of $G(\xi)$. It is shown in the appendix A.4 that the general equilibrium effect is negative if $G' > 0$.

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 $\frac{d\hat{\xi}_t^*}{d\sigma_\xi} < 0$.[31] The intuition behind this result is that increased risk makes the option to terminate the project more valuable. The empirical prediction therefore is that firms operating in a more volatile environment are insured to a smaller degree.

- $\mathcal{H}2$: 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 $\hat{\xi}_t^*$:

$$\frac{d}{d\sigma_\xi}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) = \frac{d\hat{\xi}_t^*}{d\sigma_\xi}\frac{d}{d\hat{\xi}_t^*}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) < 0, \tag{16}$$

where the inequality follows from the fact that $\hat{\xi}_t^*$ is decreasing in the volatility of the shock distribution and differentiation of expression (15) with respect to $\hat{\xi}_t^*$.

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 $\frac{d\hat{\xi}_t^*}{d(MC_t^z/P_t^z)} > 0$.[32] 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.

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

$$\frac{d}{d(MC_t^z/P_t^z)}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) = \frac{d\hat{\xi}_t^*}{d(MC_t^z/P_t^z)}\frac{d}{d\hat{\xi}_t^*}\left(\frac{d\hat{\xi}_t^*}{d\tilde{R}_t}\right) > 0, \tag{17}$$

where the inequality follows from the fact that $\hat{\xi}_t^*$ is increasing in the marginal-cost-to-price ratio and differentiation of expression (15) with respect to $\hat{\xi}_t^*$.

[31] Variations in the standard deviation σ_ξ need to be restricted to mean-preserving spreads, the result then obtains by partial integration; compare Mas-Colell, Whinston and Green (1995), chapter 6.

[32] This follows from total differentiation of condition (13), for given $\tilde{R}_t$.

4.7 Endogenous technical change

In this section, we describe the endogenous part of the productivity processes - the dynamics of $\mathcal{T}_t$. As mentioned above, we assume that the advanced projects (y_t^z) generate spill-overs on the future stock of knowledge since they embody investments in R&D, skills or the adoption of new technologies. Thus, the stock of knowledge/technologies is characterized by the difference equation:

$$\begin{aligned}\mathcal{T}_{t+1} &= \mathcal{T}_t \left(1 + \epsilon \int_0^1 y_{t,i}^z di\right) \\ &= \mathcal{T}_t \left(1 + \epsilon \int_0^1 G(\hat{\xi}_t^*) \tilde{y}_{t,i}^z di\right) \qquad \text{(18a)}\end{aligned}$$

where $0 < \epsilon \leq 1$ represents the fraction of investments in the advanced technology that involve knowledge spill-overs.

The law of motion specifies that productivity growth is increasing in productivity-enhancing investments, whereby we suppose that only successful advanced investment projects create productivity spill-overs proportional to the contemporaneous stock of knowledge.[33] Note that the specification in (18a) is essentially the same as the corresponding ones in the endogenous growth literature: the rate of technical change is governed by investments in R&D, which, in our model, are part of the investments in the advanced sector.[34] More specifically, we suppose that investments in R&D consist of expenses for research labor and capital (e.g. research lab) which are combined in a Cobb-Douglas fashion. Hence, given $\mathcal{V}$, $\mathcal{A}$ and an initial level $\mathcal{T}_0$, the current realization of the TFP-level depends on all successful past realizations of advanced investment projects. Consequently, it depends on past degrees of financial development and, if financial markets are incomplete, also on past realizations of inflation.

Note that an increase in the stock of knowledge/technology enhances the productivity in both sectors since we suppose that the new technology is not *skill biased* - it can be adopted for both types of projects.

4.8 Government policy

In order to close the model, a specification for government policy is needed. We suppose that government policy is governed by an exogenous process 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:

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

[33] Note that terminated advanced projects are liquidated before the entrepreneur exerts any effort (moral hazard). Thus, it is assumed that these *failed* projects do not cause any knowledge externality.

[34] Compare Romer (1990) or Aghion and Howitt (1992).

5 Long-run balanced growth path

In this section, we demonstrate that the equilibrium growth rate along the long-run balanced growth path is negatively related to the inflation rate. The important result of the analysis shows that this is due to a compositional effect between investment into the basic sector and investment into the advanced project.

Our setup allows to define a set of aggregate relations characterizing a competitive equilibrium in each period. The definition is given in Appendix A.3 and the corresponding competitive equilibrium relations are derived in Appendix A.2. The long-run dynamics of the model are fully governed by the law of motion of the endogenous stock of technologies in (18a) because technological progress is the only source of endogenous growth in this model:

$$\gamma = \epsilon \int_0^1 G(\hat{\xi}^*)\tilde{y}_i^z di = \epsilon y^z, \tag{20}$$

where $y^z = \widetilde{y}^z G(\hat{\xi}^*)$ is the aggregate level of (realized) output in the advanced sector.[35] In particular, (18a) concatenates a sequence of competitive equilibrium relations that we use in the following in order to demonstrate the negative relationship between the long-run equilibrium growth rate and the level of inflation. As a consequence, we need to solve for the impact of the variables in our model on the scale of successful advanced investment projects in order to analyze the determinants of the long-run balanced growth path. The analysis of the impact of inflation on the growth rate is carried out in three steps: First, we show that a drop in the cutoff value for the optimal liquidity provision $\hat{\xi}^*$ leads to a compositional change of aggregate output towards the good produced in the basic sector. Second, as already emphasized by hypothesis ($\mathcal{H}1$), an increase in the nominal interest rate reduces the optimal cutoff value and hence the insurance provided against idiosyncratic liquidity risk in the advanced sector. Moreover, because the real rental rate of capital is increasing in the nominal interest rate, the aggregate output level in the advanced sector is strictly falling in the nominal interest rate. Lastly it is shown that the equilibrium level of the nominal interest rate itself is increasing in the inflation rate.

Along the balanced growth path, the rental rates of capital and the wages in both sectors must be equal. Consequently, since both the basic technology and the advance technology employ the identical composition of capital and labor as input factors, the associated total costs in the advanced sector, which accrue when an output level of $\widetilde{y}^z$ is targeted in case of survival, amount to $V \cdot \widetilde{MC}^z = A \cdot MC^k$. Making use of the optimal input factor demands and noting that $MC^k = P^k$ in the basic sector, we obtain

$$\frac{y^z}{y^k} = \frac{V}{A} G(\hat{\xi}^*). \tag{21}$$

In other words, the markup of prices over marginal costs in the advanced sector is zero due to perfect competition if we abstract from the liquidation risk in the advanced sector. Hence, the productivity adjusted marginal costs in both sectors are equal in this case. If we differentiate (21) with respect to the cutoff-value ($\hat{\xi}^*$), we obtain the responsiveness of the

[35] In the discussion of the balanced growth path, we leave out time subscripts for notational convenience.

intermediate output ratio with respect to changes in the insurance of corporate liquidity shocks in the advanced sector:

$$\frac{d\left(\frac{y^z}{y^k}\right)}{d\hat{\xi}^*} = \frac{V}{A} g(\hat{\xi}^*) > 0. \tag{22}$$

Hence, the equilibrium ratio of investments in the advanced sector relative to the basic sector is increasing in corporate liquidity holdings ($\hat{\xi}^*$). Intuitively, relatively more projects fail in the advanced sector, on average, which reduces realized production since the projects are insured at a lower level. In addition, this also leads to a reduction of investment into the advanced technology as the advanced projects loose attractiveness in terms of expected revenues as compared to the basic technology. Moreover, it follows from $\mathcal{H}1$ that this ratio is decreasing in the nominal interest rate $\tilde{R}$. That is, less liquidity is devoted to the insurance of the advanced projects since the costs of liquidity holdings increase.

Finally, we know that the aggregated output level (y) is decreasing in the financial rate ($\tilde{R}$) since on the one hand the real rental rate of capital increases in the financial rate $\tilde{R}$ and on the other hand labor is constant.[36] Because the nominal interest rate $\tilde{R}$ reduces both, the ratio $(\frac{y^z}{y^k})$ and the aggregate output level, it immediately follows that it reduces production in the advanced sector, ie.

$$\frac{dy^z}{d\tilde{R}} < 0. \tag{23}$$

Therefore, taken together with (20), we infer that the equilibrium balanced growth rate is strictly increasing in the provision of liquidity according to the financial contract. An increase in the amount of corporate liquidity holdings enhances economic growth ($\frac{d\gamma}{d\hat{\xi}^*} > 0$). It follows from ($\mathcal{H}1$) that the long-run balanced growth rate is decreasing in the nominal interest rate ($\tilde{R}$). In fact, each level of the nominal interest rate implies a different long-run balanced growth rate: $\gamma = \gamma(\tilde{R})$. Importantly, this link between a nominal variable and TFP-growth in the case of incomplete financial markets is due to firm-level heterogeneity of investment projects. The highlighted tradeoff between risk and productivity in our framework yields an investment composition effects that results lower aggregate growth rates for higher levels of the nominal interest rate as emphasized in the following implication:

- $\mathcal{I}1$: An increase in $\tilde{R}$ leads to a lower long-run balanced growth rate γ by reducing the liquidity holdings of firms in equilibrium:

$$\frac{d\gamma}{d\tilde{R}} = \epsilon \frac{dy^z}{d\tilde{R}} < 0. \tag{24}$$

Moreover, (2) implies a type of Fisher equation in equilibrium between the nominal interest rate and the level of inflation. In particular, we can re-write (2) as follows if the economy is in a balanced growth equilibrium

[36]This can be easily demonstrated by making use of the two inter-temporal Euler equations for nominal wealth (2) and physical capital accumulation (3).

$$\tilde{R} = \pi\phi(\gamma). \tag{25}$$

In (25), $\pi = \frac{P'}{P}$ where P' denotes the price level in the next period. The deterministic function $\phi(\gamma) = \frac{u_c(c^H)}{\beta u_c(c'^H)}$ depicts the marginal rate of substitution along the long-run balanced growth path. For a standard (strictly concave) utility function $u(c^H)$, $\phi_\gamma > 0$. Total differentiation of condition (25) yields

$$\frac{d\tilde{R}}{d\pi} = \frac{\phi}{1 - \epsilon\phi_\gamma \frac{dy^z}{d\tilde{R}}} > 0, \tag{26}$$

which is strictly positive by $\mathcal{I}1$. It follows that higher rates of inflation induce a higher nominal interest rate if the economy is in a long-run balanced growth equilibrium. Consequently, economies that feature a higher level of (trend) inflation suffer from reduced long-run productivity growth. Similarly, periods of high inflation within a country reduce productivity growth while low-inflation periods cause a transition to a higher balanced growth path.

- $\mathcal{I}2$: An increase in the inflation rate π leads to a lower long-run balanced growth rate γ:

$$\frac{d\gamma}{d\tilde{\pi}} = \epsilon\frac{dy^z}{d\tilde{R}}\frac{d\tilde{R}}{d\pi} < 0. \tag{27}$$

Note that (20) implies that there exists a single long-run balanced growth rate in the (first-best) case of complete financial markets ($b = 0$). In this case, the ex ante pledgeable unit return complies with the ex post pledgeable unit return ($\hat{\xi}_t^{FB} = \hat{\xi}_t^*$), so that all investments projects in the advanced sector are re-financed: $\int_o^{\hat{\xi}_t^*} G(\xi)d\xi = 1$. Not surprisingly, it follows that the long-run balanced growth rate in a complete financial market economy dominates the growth rate in an economy that is characterized by incomplete markets. Yet, the empirical firm-level evidence from Opler et al. (1999) suggests that firms require liquidity holdings in order to invest in productive and risky projects even in the U.S. economy.

6 Empirical analysis

In this section, we employ disaggregate U.S. data to examine the specific microeconomic mechanism underlying our model. We do so in two steps, first exploiting industry-level data and then firm-level data.

6.1 Sectoral level

Data and methodology: Our model provides a set of firm-level predictions ($\mathcal{H}\infty$ - $\mathcal{H}\ni$). It is straightforward to extend our one-sector model to a multi-sector setup, whereby each individual industrial sector is a replica of the representative production structure described in Section 4.

The economy-wide TFP measure $\mathcal{T}$ can then be interpreted as industry-specific productivity measures, and the contracting implications H1 - H3 do apply not only for individual firms, but also for industrial sectors. Hence, we can empirically test our hypotheses by means of industry-level data. As an implication of $\mathcal{H}2$, we 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 (27)) then together imply that the negative relation between TFP-growth and inflation is expected to be stronger in more volatile sectors. In addition, we presume that firms operating in more productive sectors in terms of their historically realized TFP-growth have had access and are more exposed to superior investment opportunities. For given $\tilde{R}$, inspection of equation (30) reveals a link between the technology $\mathcal{V}$ available to a firm and its profitability $\frac{P^z}{MC^z}$ in case of survival; the intuitive implication is that high productivity growth goes along with high potential profitability. Hence, from $\mathcal{H}3$, profitable firms operating in industries with high realized productivity growth are expected to react more sensitively to higher inflation.

We apply 3-digit industry-level data for the U.S. to investigate these hypotheses. The productivity of U.S. industrial sectors is measured by the yearly growth rate of real value added per industry from the UNIDO (2002) industrial statistics database. The yearly data are available for 28 industries from 1963-2000.[37] The classification of 3-digit U.S. industries with respect to average volatility (standard deviation) and average growth of productivity in our sample are reported in Table 5. The correlation coefficient between these two rankings is positive 0.23 ($p - value = 0.03$) and significantly different from zero at a 1% level according to Spearman's rank correlation test. Hence, an independence of both rankings is rejected confirming that more volatile sectors are characterized by higher average productivity growth.[38] Therefore, identifying (i) volatile and (ii) strongly growing sectors with industries that are highly exposed to the advanced technology, 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 sub-samples should result from the different sensitivity of corporate liquidity holdings in response to higher inflation 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).

We control for industry specific fixed effects in all estimations. Since the first lag of the growth rate (or level) of value added is not significant at conventional levels in any specification, we employ a static panel estimation. That is, we estimate the following model:

$$y_{i,t} = \alpha + \beta_1 \Pi_{t-1} + \beta_2 (\Pi_{t-1} * DV_i) + \beta_3 X_t + \eta_i + \epsilon_{i,t}, \qquad i = 1, 2, ..., N, t = 1, 2, ..., T \quad (28)$$

where $y_{i,t}$ is the growth rate of real value added per industry, Π_{t-1} the first lag of inflation, DV_i a dummy which amounts to one for industries with an above median (first quartile) volatility/mean, X_t a vector of aggregate control variables, $N = 28$ the number of cross-sections, $T = 38$ the number of time-periods, η_i industry specific fixed effects, ϵ the error term and α

[37] Moreover, we deflate the value added series in each sector with the economy-wide GDP-deflator.

[38] 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.

and β parameters to be estimated.[39]

We cluster the error terms at the industry level so that the standard errors are robust to within group (serial) correlation.[40] Inflation is measured as the change in the economy-wide consumer price index. We include the first lag of inflation ($L.infl$) due to the potential endogeneity of contemporaneous measures. Apart, we include the contemporaneous level and the first lag of the growth rate of GDP ($GDP-growth$), the private investment share ($inv-share$) and the amount of overall credit ($credit$) as control variables. The latter variable is often used as a proxy for the degree of financial market development in the literature.

Results: The first column in Table 9 reports the correlation between the first lag of inflation and the growth rate of real value added for the full sample. We find that an 1% increase in the economy-wide rate of inflation triggers, on average, a drop in the sectoral growth rate of real value added by .96% after controlling for changes in (lagged) GDP-growth, the private investment share and the overall supply of credits. The next two columns, contrast the sensitivity of value added growth with respect to inflation in high and low volatility sectors (above/below median). In accordance with $\mathcal{H}2$, we detect that the negative impact of inflation is significant in both subsamples, but on average 61% higher in the 14 highly volatile sectors. In order to test for a statistical significance of the difference between both coefficient, we interact the lag of inflation with a dummy variable which amounts to one for high volatility industries (according to the median) and zero otherwise. Column four reveals that the interaction is negative and significant on a 10% level. That is, the distorting impact of an 1% increase in inflation aggravates, on average, by .32% if we focus on high volatility as opposed to low volatility sectors. This effect is even more pronounced if we compare the sensitivity in the seven most volatile sectors with the one in the residual 21 sectors. In particular, the sensitivity of value added growth per industry with respect to inflation is, on average, 76% higher in the seven most volatile sectors (.62/.81). The difference is significant on a 5% level. Thus, we are able to link the inflation-sensitivity of sectoral TFP-growth to the average sectoral volatility of productivity growth per industry. This systematic variation in the data is consistent with the prediction of our model summarized in $\mathcal{H}2$. Columns six to seven of Table 9 classify the impact of inflation on productivity growth according to the median and first quartile of the observed average productivity growth of a given industry in the sample. In accordance with $\mathcal{H}3$, column six reports that the negative impact of inflation is more pronounced in industries whose average productivity growth is above the sample median. Yet, the difference is not significant at conventional levels. Moreover, the coefficient not significant and even positive if we focus on the seven sectors that experienced the highest average productivity increase in the sample.

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 riskiness as measured by the sectoral volatility of value added growth ($\mathcal{H}2$) of investment portfolios 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

[39] We also included a linear time trend, but it is not significant at conventional levels. Moreover, the allowance for year fixed effects would have reduced the degrees of freedom considerably.

[40] Consequently, our results are not subject to the caveat raised by Moulton (1990).

risk. In the next subsection, we will revisit the specific implications arising from this setup on the basis of firm-level data.

6.2 Firm level

Data and methodology: Microeconomic data on firm-level behavior allow for a straightforward test of our specific theoretical mechanism. That is, our model predicts that corporate liquidity holdings are associated with investments in superior technologies. Moreover, firms react to an increase in inflation (the nominal interest rate) by reducing their liquidity holdings and by shifting their portfolio towards more secure investments ($\mathcal{H}1$). In order to test these hypotheses we employ U.S. firm-level data from Compustat. The data relate to the balance sheets of U.S. nonfinancial firms and cover the time period 1970-2000. We consider annual data since we expect that firms frequently adjust their liquidity and investment portfolios to changes in the cost of insurance.[41] Overall, we have an unbalanced panel consisting of over 2000 firms. We include the following firm level data: R&D expenses, the amount of cash and marketable securities (*corp.liquidity*), the amount of total assets (*assets*), the operating income (*opincome*), and the amount of retained earnings (*reearn*). All variables are measured in millions of dollars. Corporate R&D investments are used as a proxy for investments in superior technologies. The amount of cash and marketable securities approximate a firm's corporate liquidity holdings. The other measures serve as control variables. In particular, we expect investments in advanced technologies increase with the size of a firm (*assets*), its operating income and its retained earnings. In addition, we use the rate of inflation based on the U.S. consumer price index to investigate the effect of this macroeconomic variable on firm-level liquidity and investment portfolios.[42] We employ the GMM system estimator following Blundell and Bond (1998). Note that the mix of macro- and microeconomic data allows for a direct inspection of causality. In particular, the coefficient of inflation reflects the causal impact on (marginal) R&D expenses of a single firm since the latter has no feedback-effect on the aggregate level of inflation.

We point out that the empirical evidence provided by Opler et al. (1999), which we outlined in section 2, already supports part of our specific microeconomic mechanism. That is, the authors reveal that U.S. firms with higher growth opportunities, which are approximated by a firm's market-to-book value as well as its R&D expenses, hold on average more liquid assets (cash and marketable securities) relative to total assets. We see these empirical findings as strongly supportive of the relevance of corporate liquidity holdings for the purpose of insuring superior production activities. In this regard, we extend the analysis in Opler et al. (1999) by investigating the impact of inflation on corporate cash holdings and firm level R&D expenses.

Results: The first two columns of Table 4 confirm $\mathcal{H}1$ which states that inflation reduces corporate liquidity holdings. Accordingly, a 1% point increase in inflation reduces corporate liquidity holdings, on average, by 2.4 million \$ in the same year. The corresponding coefficient is significant on a 1% level if we employ the GMM difference estimator. Note that the long-

[41] We obtain qualitatively similar results if we focus on longer or shorter time horizons by applying 5-year averages or quarterly data, respectively. The results are available from the authors upon request.

[42] We stress that our results based on the GMM system estimator do not suffer from an aggregation bias, as outlined by Moulton (1990), since we employ heteroscedasticity- and serial correlation robust standard errors to avoid within-group correlation.

run effect is even more pronounced in this dynamic model since a reduction in the dependent variable further reduces future realization of corporate liquidity holdings. The corresponding long-run effect of a 1% point increase in inflation amounts to -9.74 million \$.[43] The negative effect of an increase in inflation is independent of variations in total assets, operating income, retained earnings or firm fixed effects. Column three and four of Table 4 display a negative correlation between inflation and firm-level R&D expenses after controlling for the other firm-level variables. Interestingly, the coefficient of inflation declines substantially if we additionally control for corporate liquidity holdings. Column five and six report our preferred estimation specification following Blundell and Bond (1998). We find that firms reduce their investments in R&D significantly in years of higher inflation. Accordingly, a 1% point increase in inflation reduces corporate R&D expenses, on average, by .19 million \$ in the same year and by 8.8 million \$ in the long-run. This distorting impact declines, on average, by 68% if we additionally control for corporate liquidity holdings. The resulting inflation coefficient is no longer significant at conventional levels. This finding reveals that the negative impact of inflation on firm-level R&D investments is transmitted via fluctuations in corporate liquidity holdings just like our theoretical mechanism suggest - compare $\mathcal{H}1$ and $\mathcal{I}2$. Moreover, in accordance with Opler et al. (1999), we detect a strong positive correlation between corporate liquidity holdings and R&D which is significant at a 1% level. We reject the presence of second order autocorrelation in all estimation specifications and the Hansen test of overidentifying restrictions supports the validity of the instruments. Hence, the estimation specifications appears to be well specified.[44] In the last two columns of Table 4, we include the overall corporate level of investments instead of specific R&D investments as the dependent variable. Our model predicts that only investments in the advanced technology are negatively affected by inflation or a reduction in corporate liquidity holdings. Indeed, the results show that inflation does not influence the overall level of corporate investments. Similarly, they are also not affected by the level of corporate liquidity holdings. Thus, the distorting impact of inflation is specific to investments in advanced technologies. Finally, note that the systematic pattern of correlation between corporate investments decisions and inflation after controlling for other firm characteristics, which is specific to investments in R&D, clearly suggests that the negative inflation coefficient is not just picking up time effects. Instead, there appears to be a systematic variation in the data supporting our hypotheses.

Summing up, the firm-level results show that inflation has a negative impact on firm-level R&D expenses. However, this effect disappears if we correctly control for corporate holdings of cash and marketable securities. Thus, the impact of inflation on firm-level investments in superior technologies is (at least partly) due to variations in corporate liquidity holdings. Moreover, inflation as well as corporate liquidity holdings do not affect the overall level of corporate investments. Hence, the distorting impact of inflation on corporate investments portfolios by means of a reduction in corporate liquidity holdings is specific to investments in advanced technologies. This empirical result directly approves the microeconomic mechanism underlying our theoretical derivations of a negative aggregate relation between inflation and long-run TFP-growth.

[43] If $\beta_1 = 2.36$ denotes the coefficient of inflation and $\rho = .7578$ the one of the lagged dependent variable the long-run effect approximately amounts to $\frac{\beta_1}{1-\rho}$.

[44] Inflation is considered as an exogenous variable (see above). The microeconomic variables are considered as (potentially) endogenous.

7 Concluding remarks

The present paper presents an endogenous growth model that combines elements of the growth and business cycle literature: it considers financial markets frictions and their interaction with short-run nominal constraints and endogenizes the productivity process via an endogenous technology choice which is catalyzed by these frictions. We demonstrate that inflation reduces long-run productivity growth in this framework. Thus, TFP-growth is partially endogenized by relating changes in the long-run balanced growth path of TFP to changes in monetary policy. The model replicates the negative empirical long-run relationship between inflation and TFP-growth as observed by Fischer (1993) and others adequately. In the empirical analysis, we present micro-econometric evidence from disaggregated sectoral and firm-level data that is consistent with our specific microeconomic mechanism underlying the macroeconomic monetary transmission channel. In particular, we detect at the industry level that the negative effect of inflation on productivity-growth per sector varies systematically with (i) the riskiness (volatility) of investments in a sector ($\mathcal{H}2$) and (ii) the average productivity-performance of a sector over the sample ($\mathcal{H}3$). The firm-level data reveal that an increase in inflation is associated with reduced corporate liquidity holdings in the U.S. economy ($\mathcal{H}1$). In addition, aggregate inflation has a negative impact on firm-level R&D expenses, whereas we are able to show that the effect is (at least partly) due to fluctuations in corporate liquidity holdings just as the theoretical model suggests. Therefore, the general equilibrium implications of the constraint optimal financial contracting scheme are consistent with micro-econometric empirical evidence. In fact, the disaggregated empirical results confirm the relevance of our specific monetary transmission channel even in developed countries such as the USA. These microeconomic interactions lead to the key insight: the short-run interplay between inflation, the financial market friction and a firm's compositional investment decision involve long-run consequences for TFP-growth. Hence, the model postulates a novel aspect of monetary transmission in that movements in the nominal interest rate are associated with changes in the long-run growth path of TFP. Since differences in TFP explain roughly 2/3 of cross-country income fluctuations, differences in trend inflation across countries represent an important factor to account for in explaining these fluctuations. This result entails strong policy implications for some (emerging) economies since changes in monetary policy regimes represent a relatively inexpensive way to catch up in terms of TFP and to encourage private sector development.

A Appendix

A.1 Financial contract

In the following, we provide the algebraic solution of the financial contract $\mathcal{C}_t = \{z_t, l_t^z, \Gamma_t(\xi_t), \tau_t(\xi_t)\}$ defined in (12).

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 $C\left(W_t^z, R_t^z; \tilde{y}_t^z\right)$ associated with a targeted production scale $\tilde{y}_t^z$. Hence, the demands for capital and labor are:

$$z_t = \frac{\alpha^z P_t^z \tilde{y}_t^z}{R_t^z} \qquad \text{and} \qquad l_t^z = \frac{(1 - \alpha^z P_t^z \tilde{y}_t^z)}{W_t^z} \tag{29}$$

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

$$C\left(W_t^z, R_t^z; \tilde{y}_t^z\right) = MC_t^z\left(W_t, R_t^z\right)\tilde{y}_t^z = \frac{1}{\mathcal{T}_t\mathcal{V}}\left(\frac{R_t}{\alpha}\right)^{\alpha}\left(\frac{W_t^z}{(1-\alpha)}\right)^{(1-\alpha)}\tilde{y}_t^z \tag{30}$$

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: 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.[45] Substituting from the binding participation constraint (12b) into the entrepreneur's net return (12a) yields:

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

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:

$$\Pi_t^F(\hat{\xi}_t) \quad = \quad \lambda_t(\hat{\xi}_t)MC_t^z(\cdot)\tilde{y}_t^z, \tag{31a}$$

[45] 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.

where:

$$\lambda_t(\hat{\xi}_t) \equiv \left[\int_0^{\hat{\xi}_t} \frac{P_t^z}{MC_t^z(\cdot)}\left(1-\xi_t\tilde{R}_t\right) dG(\xi_t) - 1\right] \tag{31b}$$

In definition (31b), $\lambda_t(\hat{\xi}_t)$ 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 (31a), 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.[46] 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 (12b), 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 (12c) is binding at the maximum pledgeable unit return:

$$\tau_t(\xi_t) = \frac{\Gamma_t(\xi_t)(1-b)P_t^z\tilde{y}_t^z}{MC_t^z(\cdot)\tilde{y}_t^z} \tag{32}$$

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 (32) into the investor's participation constraint (12b) to obtain:

$$\left[1 - \int \Gamma(\xi_t)\left((1-b) - \xi_t\tilde{R}_t\right)\frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t)\right] MC_t^z(\cdot)\tilde{y}_t^z = E_t \tag{33}$$

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 (33) implies that, given some $E_t > 0$, the expected (subject to idiosyncratic liquidity shocks) marginal return on outside investment is strictly smaller than one.[47]

[46] 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.

[47] Indeed, if this was not the case, investment would be self-financing and there would be no demand for

Solving equation (33) for the maximum investment volume conditional on a given cutoff value $\hat{\xi}_t$, allows to write the firm's investment capacity as:

$$MC_t^z(\cdot)\tilde{y}_t^z \quad = \quad \mu_t(\hat{\xi}_t)E_t, \tag{34a}$$

where:

$$\mu_t(\hat{\xi}_t) \quad \equiv \quad \frac{1}{1-\int_0^{\hat{\xi}_t}\left((1-b)-\xi_t\tilde{R}_t\right)\frac{P_t^z}{MC_t^z(\cdot)}dG(\xi_t)} \tag{34b}$$

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 (33). Finally, using (31a) and (34a), the entrepreneur's expected net payoff becomes:

$$\Pi_t^F(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t)\mu_t(\hat{\xi}_t)E_t \tag{35}$$

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 (35). It is clear that $\hat{\xi}_t^* \in [\hat{\xi}_t^0, \hat{\xi}_t^{FB}]$. Within this interval there emerges a trade-off since, on the one hand, increasing $\hat{\xi}_t$ implies that continuation is possible in more contingencies and, 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 (31b) and (34b) into (35), it is straightforward to show that the optimal continuation value $\hat{\xi}_t^*$ can be found as the solution to the following problem:

$$\min_{\hat{\xi}_t} \frac{\tilde{R}_t\int_0^{\hat{\xi}_t}\xi_t dG(\xi_t)+\frac{MC_t^z(\cdot)}{P_t^z}}{G(\hat{\xi}_t)} \tag{36}$$

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:

$$\int_0^{\hat{\xi}_t^*} G(\xi_t)d\xi_t = \frac{MC_t^z(\cdot)}{P_t^z}\frac{1}{\tilde{R}_t} \tag{37}$$

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.

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

$$\Pi_t^F(\hat{\xi}_t^*) = \frac{\frac{1}{\tilde{R}_t} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \frac{(1-b)}{\tilde{R}_t}} E_t = \frac{\hat{\xi}_t^{FB} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \hat{\xi}_t^0} E_t \tag{38}$$

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 an 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.

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:

$$\bar{D}_t = \hat{\xi}_t^* P_t^z \tilde{y}_t^z \tag{39a}$$

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

$$D_t^* = \left[\int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t \right] P_t^z \tilde{y}_t^z < \bar{D}_t \tag{39b}$$

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 4.5. 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.[48]

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 ξ_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.

A.2 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:

[48]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.

$$Q_t + (1-\eta)A_t = P_t c_t, \tag{40}$$

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):

$$M_{t+1} = \tilde{R}_t[M_t - Q_t + J_t] + \Upsilon_t + R_t^k k_t + R_t^z z_t + W_t^{k,H} h_t^{k,H} + W_t^{z,H} h_t^{z,H}, \tag{41}$$

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 re-channelled 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 (4), and (iii) of the aggregate cash constraint (40), one obtains:

$$M_{t+1} = M_t + \mathcal{J}_t + \Big\{(1-\eta)A_t - [W_t^{k,E} h_t^{k,E} + W_t^{z,E} h_t^{z,E} + (\tilde{\Pi}_t^F(\hat{\xi}_t^*) - 1)E_t]\Big\} \tag{42}$$

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:

$$A_{t+1} = \tilde{\Pi}_t^F(\hat{\xi}_t^*)E_t + W_t^{k,E} h_t^{k,E} + W_t^{z,E} h_t^{z,E}, \tag{43}$$

where $E_t = \eta A_t$. In order to derive a convenient expression for the evolution of aggregate wealth, we add equations (41) and (43) and employ the zero-profit condition mentioned above as well as condition (4) to obtain:

$$M_{t+1} + A_{t+1} - (D_t + E_t) = P_t y_t, \tag{44}$$

which gives immediately rise to a modified quantity relation:

$$P_t = \frac{M_{t+1} + A_{t+1} - (D_t + E_t)}{y_t} \tag{45}$$

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.[49]

[49] 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.

A.3 Equilibrium

Definition 1 (Competitive Equilibrium) *Given initial conditions* $\{k_0, z_0, A_0, M_0\}$ *and realizations of monetary policy* $\{\mathcal{J}_t\}_{t=0}^{\infty}$ *and idiosyncratic shocks* $\{\xi_t^i\}_{t=0}^{\infty}$*, a competitive equilibrium is a list of allocations* $\{c_t^H, h_t^{k,H}, h_t^{z,H}, k_t, z_t, Q_t, M_{t+1}\}_{t=0}^{\infty}$ *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 economy-wide aggregates* $\{c_t, l_t^k, l_t^z, \overline{L}, \overline{K}, y_t^k, y_t^z, y_t\}_{t=0}^{\infty}$ *and of prices* $\{P_t, P_t^z, P_t^k, W_t, W_t^k, W_t^{k,H}, W_t^{k,E}, W_t^z, W_t^{z,H}, W_t^{z,E}, R_t, R_t^k, R_t^z, \tilde{R}_t\}_{t=0}^{\infty}$ *such that:*

1. *given prices, the allocation solves the household problem (1) as well as the basic and advanced firm problems (8) and (12);*

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.*

Note that the competitive equilibrium is not efficient due to the entrepreneurial moral hazard problem that leads to the termination of ex-post efficient projects and the externality of knowledge on the future productivity of investment projects.

A.4 The responsiveness of corporate liquidity to changes in the financial rate ($\mathcal{H}1$)

In the following, we demonstrate that the general equilibrium effect of the financial rate ($\tilde{R}_t$) on the corporate provision of liquidity $\hat{\xi}_t^*$ is negative as summarized in $\mathcal{H}1$. Therefore, we assume a specific functional form for the distribution of liquidity shocks: $G(\xi) = \xi^{\frac{1}{\phi}}$, $\phi > 0$. Hence, in accordance with Aghion et al. (2005), we assume that the distribution of liquidity shocks is monotonically increasing in ξ.

Moreover, the relative demand for both intermediates given by (6) leads to the following equilibrium condition: $\frac{y_t^z}{y_t^k} = \frac{1-\zeta}{\zeta}\left(\frac{P_t^z}{P_t^k}\right)^{-\rho}$. If we substitute for the price ratio by $\frac{P_t^z}{P_t^k} = \frac{A}{V}\frac{1}{\tilde{R}_t \int_0^{\hat{\xi}_t^*} G(\xi)d\xi}$ from (13), we get:

$$G(\hat{\xi}_t^*) = \frac{1-\zeta}{\zeta}\left(\frac{A}{V}\right)^{1-\rho}\left(\tilde{R}_t \int_0^{\hat{\xi}_t^*} G(\xi)d\xi\right)^{\rho} \tag{46}$$

Taking the total derivative of (47) and noting that the functional form for the distribution of liquidity shocks implies that $\frac{dG(\hat{\xi}_t^*)}{d\hat{\xi}_t^*}\frac{\hat{\xi}_t^*}{G(\hat{\xi}_t^*)} = \frac{1}{\phi}$ and $\frac{d\int_0^{\hat{\xi}_t^*} G(\xi)d\xi}{d\hat{\xi}_t^*}\frac{\hat{\xi}_t^*}{\int_0^{\hat{\xi}_t^*} G(\xi)d\xi} = \frac{1+\phi}{\phi}$, we obtain:

$$\frac{d\hat{\xi}_t^*}{d\tilde{R}_t} = \frac{\tilde{R}_t}{\hat{\xi}_t^*}\frac{\rho\phi}{1-\rho(1+\phi)} < 0 \tag{47}$$

Thus, given that the functional form for the distribution of liquidity shocks is monotonically increasing in ξ, the general equilibrium provision of corporate liquidity is decreasing in the nominal financial rate $\tilde{R}$ as stated in $\mathcal{H}1$.

A.5 Construction of the TFP measure

We construct the series of aggregate TFP-growth, as a residual from the human capital augmented Solow-model.[50] We follow the basic specification in Caselli (2005) who computes TFP levels across countries for the year 1996. That is, we employ the production function: $y_t = A_t k_t^{\alpha} h_t^{1-\alpha}$, where A is the level of TFP, y the real GDP per worker in international dollars, k the physical capital stock per worker and h the human capital stock per worker. The first measures stem from the Penn World Tables (PWT) and the latter from Barro and Lee (2001), respectively. The capital stock (K) is computed with the perpetual inventory method, whereby the depreciation rate (δ) is set to 6% and the initial capital stock is computed as $K_0 = \frac{I_0}{g+\delta}$. g is the average geometric growth rate for the investment series between the first year with available data and 1970.[51] The stock of human capital is derived according to Hall and Jones (1999): $h = \exp \phi(s)$, where s is the average years of schooling in the population over 25 year old and the function $\phi(s)$ is piecewise linear with slope 0.13 for $s \leq 4$, 0.10 for $4 < s \leq 8$ and 0.07 for $8 < s$. We incorporate a share of private capital per worker of 1/3 ($\alpha = 1/3$). Caselli (2005) provides a comprehensive discussion of various robustness tests to this procedure in a development accounting framework. He shows that the explanatory power of the TFP-series (2/3) to explain variations in GDP is robust to the inclusion of different measures for the quality of human capital or different estimation procedures for k.[52] Therefore, we follow his basic specification. We compute the TFP series for 88 countries from 1970-1980. Our TFP-series complies with Caselli (2005) for 1996. We drop the TFP-measure for the first ten observations and start the series in 1980 in order to minimize the influence of the initial capital stock on our results. The rankings of the TFP-measures across countries and years yield plausible results.[53]

[50] The inclusion of various control variables reduces the effective size of the panel to a minimum of 68 countries in some estimations.

[51] The investment series starts for 54 countries in 1950, for 17 in 1955 and for the remaining 17 in 1960.

[52] We note that this explanatory power decreases significantly if α exceeds 0.5, which, however, does not comply with existing empirical estimates.

[53] The five highest (log-) TFP level exhibit Ireland in 2000-1997, respectively, and Italy in 1999. The 50 lowest TFP-levels are measured in Zaire, Malawi, Romania, Zambia, Rwanda, Lesotho and China for different time periods, respectively. The complete ranking is available from the authors on request.

Table 1: USA: Sectoral volatility and mean of growth in value added per worker

	BEA				Compustat			
Industries	vol	rank	growth	rank	vol	rank	growth	rank
Food products	2.8	28	6.7	15	0.49	20	0.08	21
Beverages	4.1	26	6.2	18	0.47	24	0.06	22
Tobacco	9.5	8	9.8	2	0.52	15	0.12	14
Textiles	6.6	19	5.2	24	0.52	16	0.12	15
Wearing apparel, except footwear	5.5	23	3.9	26	0.55	6	0.06	24
Leather products	10.8	6	3.4	27	0.47	25	0.04	27
Footwear, except rubber or plastic	8.0	14	0.6	28	0.66	1	0.05	25
Wood products, except furniture	12.3	4	7.1	12	0.53	14	0.19	8
Paper and products	7.0	17	7.5	9	0.50	18	0.09	18
Printing and publishing	4.6	25	8.2	5	0.55	5	0.17	9
Petroleum refineries	22.4	1	8.7	4	0.37	28	0.06	23
Misc. Petroleum and coal products	9.0	10	7.5	8	0.49	21	0.21	7
Industrial chemicals	9.8	7	6.6	16	0.49	22	1.30	1
Other chemicals	3.7	27	7.5	7	0.51	17	0.09	20
Plastic products	9.1	9	11.4	1	0.53	12	0.14	11
Rubber products	6.2	20	5.4	23	0.50	19	0.09	19
Pottery, china, earthenware	8.8	12	6.4	17	0.53	13	0.47	4
Glass and products	5.8	22	6.0	21	0.57	3	0.23	6
Other non-metallic mineral products	6.9	18	6.0	22	0.44	27	0.04	26
Iron and Steel	13.2	3	4.3	25	0.46	26	0.03	28
Non-ferrous metals	14.8	2	6.7	13	0.48	23	0.10	17
Fabricated metal products	5.5	24	6.1	20	0.54	10	0.11	16
Machinery, except electrical	8.5	13	7.2	11	0.55	7	0.29	5
Professional & scientific equipment	11.8	5	9.5	3	0.57	2	0.84	2
Machinery, electric	7.8	15	7.9	6	0.56	4	0.16	10
Transport equipment	8.9	11	6.7	14	0.53	11	0.12	12
Furniture, except metal	7.1	16	7.3	10	0.55	8	0.12	13
Other manufacturing products	5.9	21	6.2	19	0.54	9	0.50	3

BEA: rank correlation coefficient of 0.232 ($p - value = 0.030$); Compustat: rank correlation coefficient of 0.479 ($p - value = 0.010$).

Table 2: Aggregate data: 5-year-averages: Inflation & TFP growth

	TFP growth							
	OLS	LSDV	GMM-sys	GMM-sys	GMM-sys	GMM-sys	GMM-sys	GMM-sys
infl	-.0014***	-.0009***	-.0020***	-.0016**	-.0022***		-.0059**	-.0646***
	(-7.33)	(-4.17)	(-2.74)	(-2.44)	(-2.96)		(-2.05)	(-2.85)
infl-vol						-.0009**	.0026*	
						(-2.01)	(1.66)	
credit	.2479	-.7932	.7770	-.5247	.8965	.7517	.0139	.4846
	(.54)	(-.93)	(.69)	(-.46)	(.81)	(.66)	(.01)	(.58)
trade	.0021	.0154	.0066	.0027	.0047	.0079	.0076	
	(.82)	(.96)	(1.05)	(.35)	(.87)	(1.22)	(1.38)	
ki				.1309***				
				(2.21)				
ppr	.3130***	.1759	.4452***	.3656**	.4182**	.4294**	.4779***	-.2293*
	(3.58)	(1.26)	(2.94)	(2.53)	(2.81)	(2.92)	(3.32)	(-1.71)
kg	-.0113	-.0687	-.0243	-.0145	-.0214	-.0257	-.0145	-.0606
	(-.59)	(-.79)	(-.87)	(-.54)	(-.81)	(-.95)	(-.54)	(-1.07)
tot	-.0066	-.0013	-.0055	-.0164	-.0058	-.0062	-.0047	.2247**
	(-.87)	(-.12)	(-.59)	(-1.54)	(-.66)	(-.67)	(-.51)	(2.18)
lag dep. var.	-.0049***	-.0229***	-.0180***	-.0183***	-.0162***	-.0171***	-.0151***	-.6202***
	(-3.24)	(-5.28)	(-5.53)	(-5.07)	(-5.52)	(-5.41)	(-5.65)	(-4.20)
time-FE	-	-	-	-	yes	-	-	
Cou./Obs.	86/363	86/363	86/363	86/363	86/363	86/362	86/362	22/107
1. auto-cor.	-	-	0.001	0.002	0.001	0.001	0.001	0.034
2. auto-cor.	-	-	0.127	0.129	0.175	0.113	0.211	0.385
Hansen-test	-	-	0.122	0.287	0.161	0.108	0.195	0.939

We specify inflation, inflation-volatility, credit, trade and the investment share as endogenous and property rights, government share and terms of trade as exogenous variables in the GMM system estimation. Inflation volatility is measured by the average standard deviation of yearly inflation rates. Predetermined lagged level of TFP as lagged dependent variable (lagged TFP-level labelled as endogenous according to Hansen test in OECD sub-sample).

Table 3: Sectoral data
Inflation-sensitivity in volatile/high-growth vs. non-volatile/low-growth sectors

	Growth rate of value added						
	full sample	vol>med	vol<1.qua	full sample	full sample	full sample	full sample
inflation	-.9632***	-1.19**	-.7390***	-.8014***	-.8107***	-.8700***	-1.02***
	(-4.20)	(-2.69)	(-5.83)	(-3.84)	(-3.73)	(-3.51)	(-4.25)
infl∗dvol				-.3235*	-.6167**		
				(-1.65)	(-2.58)		
infl∗dmean						-.1981	.2379
						(-.97)	(1.14)
GDP-growth	1.20***	1.29**	1.10***	1.19***	1.19***	1.20***	1.19***
	(4.36)	(2.67)	(3.92)	(4.36)	(4.34)	(4.36)	(4.35)
L.GDP-growth	-.7851***	-.8938*	-.6764***	-.7851***	-.7869***	-.7839***	-.7858***
	(-2.92)	(-1.71)	(-4.11)	(-2.92)	(-2.93)	(-2.92)	(-2.92)
credit	-11.46***	-15.01**	-7.91***	-11.46***	-11.52***	-11.42***	-11.49***
	(-3.26)	(-2.23)	(3.86)	(-3.26)	(3.27)	(3.52)	(-3.27)
inv-share	.5734**	.8181	.3287	-.6305	.5734**	.5720**	.5741**
	(2.04)	(1.55)	(1.64)	(2.04)	(2.05)	(2.03)	(2.04)
Ind./Obs.	28/946	14/473	14/473	28/946	28/946	28/946	28/946

The correlation coefficient between the volatility- and mean rankings amounts to .23 (s.e. 0.03) according to Spearman's rank correlation test.

1963-2000 yearly data. Always include a constant. Heteroscedasticity- and serial correlation robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.

Table 4: U.S. firm-level yearly data: R&D versus investments

	Corporate liquidity		R&D				R&D/inv	R&D/asset	inv/asset
	OLS	GMM-sys	OLS	OLS	GMM-sys	GMM-sys	LSDV	LSDV	LSDV
inflation	-2.86***	-4.08***	-.4157***	-.3716***	-.5435***	-.3332***	-.6739***	-.0992***	.2161***
	(-8.10)	(-6.96)	(-7.70)	(-7.16)	(-3.56)	(-2.67)	(-3.19)	(6.15)	(6.15)
corp. liquidity				.0167***		.0510***			
				(4.29)		(2.78)			
assets	.0084**	-.0064	-.0001	-.0007	-.0037	-.0020	-4.9E-04*	-3.7E-04***	-.0002***
	(1.98)	(-.40)	(-.06)	(-.75)	(-1.35)	(-.62)	(-1.64)	(-4.88)	(-3.72)
opincome	-.0192	-.0327	.0068**	.0062**	.0288***	.0170*	.0002	.0001*	-.0001
	(-.42)	(-.50)	(2.36)	(2.03)	(3.13)	(1.92)	(.73)	(1.77)	(-.28)
reearn	.0168*	.0441	-.0006	-.0017*	-.0049	-.0058	-.0002	3.0E-04*	.0006***
	(1.76)	(1.30)	(-.60)	(-1.74)	(-1.01)	(-1.43)	(-1.47)	(1.74)	(5.70)
inv	-.0003	.0333	-.0001	.0005	.0060	.0018			
	(-.03)	(.95)	(-.09)	(.33)	(1.18)	(.33)			
lag-dep.-var.	.9039***	.8369***	1.02***	1.00***	.9840***	.9202***			
	(31.11)	(11.35)	(63.72)	(56.92)	(16.22)	(11.90)			
Firms	6972	6972	6978	6978	6978	6978	7710	7711	7711
Observations	56424	56424	56445	56445	56445	56445	65067	65147	65074
1. auto-cor.	.978	.000	.244	.212	.001	.000			
2. auto-cor.		.487			.788	.722			
Hansen-test		.442			.107	.135			

The maximum lag is restricted to 10 years in order to reduce the size of the IV matrix.

1970-2000 yearly data. Heteroscedasticity robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.

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