

# Towards a theory of total factor productivity (-growth): Monetary policy, short-run fluctuations and long-run consequences

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PRELIMINARY VERSION

This version: 06.10.2006

## Abstract

This paper demonstrates a negative relation between short-run nominal fluctuations and long-run productivity growth. First, we employ (country) panel data to investigate the robustness of a negative causal effect of inflation on long-run TFP-growth. Second, we develop an endogenous growth model whose key ingredients are (i) a firm-level technology choice between a return-dominated but secure and a more productive but risky project, (ii) an agency problem which gives rise to financial market incompleteness and (iii) a cash-in-advance constraint for households that incorporates a costly short-run provision of nominal assets in equilibrium even under flexible prices. The model generates a long-run effect of monetary policy on total factor productivity (TFP): nominal short-run fluctuations affect the costs of corporate insurance against risky (productive) projects and hence a firm's choice of technology. Thus, economies (time periods) that feature a higher level of inflation are predicted to exhibit a lower long-run TFP-level. Moreover, we show that inflation reduces the long-run balanced growth path of TFP if investments in the superior technology represent (at least partly) firm-level R&D expenses which enhance the economy's future productivity. That is, each level of inflation is associated with a different long-run balanced growth path as long as financial markets are incomplete. Finally, we apply sectoral and (U.S.) firm level dynamic panel data to test the relevance of our specific microeconomic mechanism.

## 1 Introduction

Does inflation reduce long-run economic growth? If so, what is the key transmission mechanism relating short-run nominal fluctuations to long-run growth? To answer these questions, we provide empirical evidence - in accordance with Fischer (1993) and others - that inflation reduces long-run productivity growth. Thereafter, we develop a theoretical explanation for the 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 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.<sup>1</sup> Accordingly, variations in TFP explain about 2/3 of the variations in income across countries. Against this background, substantial efforts have been devoted to endogenize what Abramovitz (1956) calls the "measure of our ignorance" (TFP).<sup>2</sup> The effect of nominal fluctuations 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 influences short-run movements of real variables, but a coherence between nominal fluctuations and long-run productivity growth is largely ignored. In fact, most approaches treat shocks to monetary policy and technology as orthogonal even in the short-run. Summing up, the determinants of growth and cycles are mostly regarded as two separated entities.<sup>3</sup>

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 framework leads to a type of *inflation tax* on productivity-enhancing investments due to a complementarity between corporate liquidity holdings (nominal assets) and a firm's ability to invest in productive but risky projects. 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 technologies: a safe, but return-dominated ("basic") technology and a superior ("advanced") technology which yields higher expected returns, but is subject to idiosyncratic liquidity shocks. We attribute productivity-enhancing investments (e.g. R&D) to the advanced technology as these types of investments are generally considered to be more productive, but also more risky. Therefore, expenses for the advanced technology 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

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<sup>1</sup>Caselli (2005) provides an exhaustive survey of recent contributions to development-accounting and investigates the robustness of the results in various dimensions.

<sup>2</sup>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).

<sup>3</sup>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.*"

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 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 knowledge. Since the latter involves a positive productivity externality, changes in the short-run nominal interest rate imply different long-run balanced growth paths of TFP. Hence, the model postulates a novel aspect of monetary transmission in that differences in monetary policy across countries and time periods create long-run differences in TFP(-growth).<sup>4</sup>

Our empirical macroeconomic evidence demonstrates the robustness of this negative empirical relation. We apply dynamic panel techniques following Arellano and Bond (1991) and Blundell and Bond (1998) that allow some inspection of causality. Accordingly, we find that inflation or the short-run nominal interest rate reduce long-run TFP-growth, whereby their 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 sectoral and firm-level panel data. 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) inflation reduces corporate liquidity holdings which, in turn, reduces firm-level investments in R&D.

There exist approaches in the literature that link long-run (GDP-) growth to short-run fluctuations. In this regard, King et al. (1988) incorporate constant returns to capital in a real business cycle model showing that temporary shocks can have permanent effects. Similarly, Aizenman and Marion (1993) develop a negative relation between volatility and GDP-growth due to the existence of investments irreversibilities. More recently, Fatas (2001) relates long-run growth to short-run business cycles. He embeds aggregate demand externalities 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 the above contributions, our setup is based on an endogenous form of financial market incompleteness which allows us to test for the empirical relevance of our approach. In addition, the permanent effects in these models are transmitted via the aggregate quantity of investments, instead of their quality. In this regard, Ramey and Ramey (1995) measure a negative empirical correlation between the level of macroeconomic volatility and the trend of GDP-growth. However, they reveal that this finding is robust to the inclusion of the investment share of GDP.

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<sup>4</sup>We stress that even in the absence of a knowledge externality from advanced sector investments, movements in the short-run nominal interest rate cause changes in the aggregate level of TFP (not its growth rate).

Hence, the effect of volatility on growth is found to be 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 amplifies 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.

These contributions analyze the impact of credit constraints on the economy's cyclical productivity dynamics, but do not take into account a potential interplay with nominal variables. Moreover, one disadvantage with above approaches is that their implications critically hinge on the *assumption* that uninsured idiosyncratic investment risk evolves in a countercyclical fashion. In order to improve along this dimension, it is important to carefully specify the source of market incompleteness which gives rise to uninsured idiosyncratic risk. In our study, we will do so by embedding the contracting problem discussed in Holmstrom and Tirole (1998). The question addressed there is whether private claims provide enough liquidity to guarantee the efficient functioning of the productive sector. In contrast to the classical theory of finance, where there is no corporate demand for liquidity since firms, at any time, can issue claims up to the full present value of their expected future returns, the paper introduces an entrepreneurial moral hazard problem that creates a demand for liquidity in the form of advance financing. If this corporate demand for liquidity is matched with an endogenous supply of funds, the key observation to be drawn is that the same agency problem that limits the scope for ex post refinancing also limits the amount of resources that can be raised for investment purposes ex ante.

In the context of economic growth, 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 constrained by risk diversification opportunities. The model explains why output volatility is high in less developed countries and declines 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 (short-run) interplay between monetary policy and a specific financial market friction. That is, endogenous incomplete financial markets in our model translate monetary policy (regimes) into long-run productivity movements instead of being a cause of movements in productivity trends per se.

The empirical literature on inflation and growth employs cross-country (panel) regressions with low frequency data.<sup>5</sup> In this context, Bruno and Easterly (1998) and Easterly et al. (2005)

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<sup>5</sup>Important contributions in this branch of research include De Gregorio (1992, 1993) and Barro (1996).

detect that the negative relation between GDP-growth and inflation is mainly due to *inflation outliers*. They assume different threshold levels (e.g. 20%, 40%) in inflation and find that the negative effect is only robust in high-inflation countries. In addition, Fischer (1993) also assesses the relevance of non-linearities in the inflation-growth nexus. He uses splines (with breakpoints at 15% and 40%) and finds, however, 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, by considering sample variations across periods predominated by demand (1960-1972) or supply (1973-1988) shocks, he examines the potential endogeneity of inflation.<sup>6</sup> In line with the established literature, he starts from the presumption that adverse supply shocks are the main source of the endogeneity of inflation (while an 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 and for our purpose most importantly, the author decomposes GDP growth into its components and detects a robust negative relation between inflation the growth rate of TFP. This last result implies that, even after controlling for factor accumulation and employment, the negative effect of inflation on growth persists. In the next section, we will complement the work of Fischer (1993) and investigate the TFP-growth inflation nexus employing alternative econometric methods and various additional robustness checks.

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 US firms.<sup>7</sup> 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.<sup>8</sup> Opler et al. (1999, p.21) conclude: *"This is consistent with the view that firms will hold more cash in order to protect the value of growth options and to avoid the high transaction costs associated with raising capital in the face of information asymmetries."* 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

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<sup>6</sup>The difficulty in identifying a causal relation between inflation and growth stems from the lack of appropriate external instruments for inflation. For cross-country regressions, a possible instrumental variable approach is due to Cukierman et al. (1993) who incorporate measures of central bank independence as instrumental variables and detect negative correlations with economic growth. Our own approach in Section 2 circumvents the problem by applying dynamic panel regressions, thus relying on internal instruments whose validity is testable.

<sup>7</sup>The background for most theoretical and empirical studies of corporate cash holdings is the presumption that external finance is costly and that firms hold liquid assets in order to survive bad times and to have funds readily available if an investment opportunity arises. The benefits of corporate liquidity must then be balanced against its costs which arises as a consequence of a liquidity premium.

<sup>8</sup>We interpret these latter features - high growth potential and risky cash flows - as the identifying characteristics of what we label "advanced" technology.

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 category for the transmission of macroeconomic shocks and in particular of fluctuations in nominal variables like the rate of inflation or the nominal interest rate.

The rest of the paper is organized as follows. Section 2 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 5, 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 Inflation- TFP-growth nexus

In this section, we complement the work of Fisher (1993) and apply a different econometric method to investigate the inflation- TFP-growth nexus. Moreover, we inquire the robustness of this empirical relation with respect to the inclusion of various institutional and financial control variables and sample variations. The aggregate empirical analysis is based on an unbalanced panel data set consisting of 88 countries from 1970-1999. We employ 5-year averages to smooth out business cycle effects which reduces the time dimension to six observations per country.<sup>9</sup> We construct the TFP series following Caselli (2006). In line with the empirical growth literature, we include the lagged level of TFP as a lagged dependent variable in the growth regression.<sup>10</sup> Accordingly, we apply a dynamic panel data model. Therefore, we employ the method developed by Blundell and Bond (1998) which is constructed to yield consistent estimates in dynamic panels. Our strategy to address the problem of a potential endogeneity of inflation is twofold. First, the procedure of Blundell and Bond (1998), which is based on the general method of moments (GMM), instruments predetermined and endogenous variables with the suitable corresponding lags of these variables. Hence, we use appropriate lags of inflation to instrument for its contemporaneous measures. Moreover, the procedure provides a test of overidentifying restrictions (and second order autocorrelation) to check for the validity of the instruments. Second, 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 (*credit*) in an economy.<sup>11</sup> Furthermore, we account for the following institutional control variables: the government share, the amount of trade in goods as % of GDP, the terms of trade and an index of overall property rights. A detailed description of the growth accounting methodology, the data as well as the dynamic panel techniques are provided in the appendix.

In Figure 1, we plot annual data for inflation and TFP-growth using the subset of 22 OECD countries from 1980-2000.<sup>12</sup> The scatter-plot illustrates a negative bivariate correlation between

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<sup>9</sup>Specifically, we use the following non-overlapping time averages: 1970-1974, 1075-1979, ..., 1995-1999.

<sup>10</sup>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).

<sup>11</sup>We note that all of our results are robust to the inclusion of alternative proxies such as the amount of liquid liabilities, the rate of stock market trade, the amount of financial deposits (*fin*) or the real interest rate. The results are available from the authors upon request.

<sup>12</sup>The informational value is very limited if we exploit the entire panel of 88 countries since most inflation-

the two. However, this relation may be due to periods of excessive inflation rates above 20% or 40% as suggested by Bruno and Easterly (1998). Therefore, we focus on a smaller subset of 19 OECD countries from 1990-2000 in Figure 2. The highest observable inflation rate in this sample amounts to roughly 15%. Yet, the data still indicate a negative correlation between the two series. In this respect, the simple scatter-plots already suggest that the negative aggregate correlation between inflation and TFP-growth does not exclusively stem from inflation-outliers.

In Table 2, we investigate the reduced-form relation between the two aggregate series controlling for spurious correlation and endogeneity. 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.<sup>13</sup> 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 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.<sup>14</sup> Column five shows that our results are robust to the inclusion of time fixed effects which control for common aggregated shocks over time. 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.<sup>15</sup> 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%. The negative coefficient is significant

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observations are within the same range apart from some extreme outliers due to periods of hyperinflation.

<sup>13</sup>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 only 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.

<sup>14</sup>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.

<sup>15</sup>Uncertainty is measured as the average annual standard deviation for a corresponding 5-year-interval.

on a 1% level. The coefficient in the OECD sub-set is more pronounced since many countries suffered from periods of hyperinflation if we consider the full sample.<sup>16</sup> That is, excessive rates of inflation reduce the marginal effect of a 1% (point) increase in inflation substantially. 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. In the following, we introduce an endogenous growth model which accounts for the interplay of short-run nominal and financial frictions to illuminate the long-run negative causation running from inflation to TFP-growth. Thereafter, we provide micro-econometric evidence which is consistent with the model specific implications.

### 3 The model

In this section, we propose a closed-economy growth model of endogenous technological change which features two short-run frictions: (i) a financial friction for risky investment projects and (ii) the necessity of nominal assets holdings in order to consume at the end of the period (cash-in-advance constraint). These temporary frictions lead to a positive short-run demand and supply of nominal assets (liquidity) and hence a positive short-run nominal interest rate even under flexible prices. 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.<sup>17</sup> We assume that investments in the advanced technology generate a positive externality on the future stock of knowledge/technologies available in the economy. There exist various interpretations of what the two types of investments 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.<sup>18</sup> 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  $\xi_t^i$  to the subset of firms operating the advanced technology. We now turn to a detailed description of the environment in which the economy's agents interact and define their relevant decision problems as well as the long-run balanced growth path of the economy.

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<sup>16</sup>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.

<sup>17</sup>As a general rule, variables pertaining to the basic sector are indicated by the variable/superscript  $k$ , while  $z$  is the relevant indicator for the advanced sector.

<sup>18</sup>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.

### 3.1 Households

The economy is populated by a unit mass of infinitely-lived, risk averse households.<sup>19</sup> 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  $(\tilde{R}_t - 1)$ .<sup>20</sup> 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:  $\bar{h}^H = h_t^{k,H} + h_t^{z,H}$ .<sup>21</sup> 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:

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

subject to the cash constraint:

$$Q_t \geq P_t c_t^H, \quad (1b)$$

and an equation describing the evolution of nominal assets:

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

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

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

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

<sup>19</sup>Where necessary, variables pertaining to the household sector will be denoted with a superscript  $H$ .

<sup>20</sup>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  $t^+$ ).

<sup>21</sup>Since households care only about their aggregate labor and capital supply, it follows that, in all states of the world, the sectoral wage rates and rental rates of capital must be identical:  $W_t^{k,H} + W_t^{z,H} = W_t^H$  and  $R_t^k + R_t^z = R_t$ .

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

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

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

An immediate implication of the two equations (3) is that the sector-specific interest rates must be equal in expectation, i.e.  $E_t\{R_{t+1}^k\} = E_t\{R_{t+1}^z\} = E_t\{R_{t+1}\}$ .

### 3.2 Entrepreneurs

Apart from households, there is a unit mass of risk neutral entrepreneurs, each one capable of running a specific project associated with the advanced production technology.<sup>22</sup> At the beginning of each period, a mass  $(1 - \eta)$  of new-born entrepreneurs enters the economy without any initial wealth and replaces an equal measure of retiring entrepreneurs.<sup>23</sup> The remaining measure  $\eta$  of incumbent entrepreneurs stays active. An individual entrepreneur arrives in period  $t$  with an amount  $A_t^i$  of nominal wealth. Then, if she receives a random exit signal, she waits until the end of the period to simply consume her accumulated wealth such that  $A_t^i = P_t c_t^{E,i}$ . In contrast, new entrants and entrepreneurs who have not received the exit signal have no consumption motive; rather, each active entrepreneur inelastically supplies her (unit) labor endowment  $h_t^E = h_t^{k,E} + h_t^{z,E} = 1$  and thus augments her nominal wealth  $A_t^i$  by her current wage earnings  $W_t^E$ . 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.

### 3.3 Financial intermediary

The financial intermediary (equivalently, a perfectly competitive financial sector) receives the time  $t^-$  financial deposits  $M_t - Q_t$  from the households as well as lump sum cash injections  $\mathcal{J}_t$  from the monetary authority. These funds are supplied to the loan market at a gross nominal interest rate  $\tilde{R}_t$ . 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:

$$M_t - Q_t + \mathcal{J}_t = D_t \quad (4)$$

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<sup>22</sup>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.

<sup>23</sup>Where necessary, variables pertaining to the entrepreneurial sector will be denoted with a superscript  $E$ .

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 3.5. Two key implications of that contracting scheme are that firm bankruptcy is an equilibrium phenomenon and that the intermediary must commit funds to individual advanced sector projects before these projects' respective liquidity needs are known. Therefore, it is important to recognize that the financial intermediary is able to pool idiosyncratic risks across the advanced sector firms. As a consequence, it is sufficient for the financial intermediary to break even on an individual credit relationship in expectation. At the end of the period, the intermediary receives the returns on its lending and financial investment activity and pays the amount  $\tilde{R}_t[M_t - Q_t + \mathcal{J}_t]$  to the households in return for their deposits.

### 3.4 Firms

In our economy, production activities proceed in 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.

#### 3.4.1 Market good

The market good producers employ the following CES aggregation technology:

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

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  $P_t$ :

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

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:

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

### 3.4.2 Intermediate goods

There are two perfectly competitive sectors producing intermediate goods. Both sectors employ capital as well as labor as input goods, but are characterized by different technologies. On the one hand, there is a safe, but return-dominated ("basic") technology; the other ("advanced") technology yields a higher potential return, but is subject to idiosyncratic liquidity shocks. The scope for an individual advanced firm's insurance against this idiosyncratic liquidity risk is endogenously determined via the financial contract described in Section 3.5. The need for this insurance arises as a consequence of an entrepreneurial moral hazard problem 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 ( $\mathcal{T}_t$ ).<sup>24</sup> In particular, we suppose that a fraction  $\epsilon$  of advanced sector output induces productivity-enhancing improvements. 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 monopolistic rent-seeking behavior, but due to the incentives for firms to optimize the composition of their investments. That is, the risk associated with R&D investments together 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 monopoly rents, but its superior productivity together 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:

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

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

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

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<sup>24</sup>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.

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

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

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:

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

Finally, the price for the basic intermediate good is:

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

**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<sup>25</sup> which may trigger the 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 given by a Cobb-Douglas production function under constant returns to scale:

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

Each advanced firm is run by an individual entrepreneur who brings the amount  $E_t^i$  as private equity into the firm. The firm's production plan and its hedge against liquidity shocks  $\xi_t^i$ , which are distributed according to a continuous distribution function  $G(\xi_t^i)$  with associated (strictly positive) density  $g(\xi_t^i)$ , are then determined as part of a constrained-efficient contract between the entrepreneur and the financial intermediary. In particular, the liquidity provision stipulated by the financial contract will be seen to pin down a threshold value  $\hat{\xi}_t^*$  up to which liquidity shocks are covered; this threshold, in turn, determines an individual advanced firm's

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<sup>25</sup>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.

ex ante survival probability  $G(\hat{\xi}_t^*)$ . Since the financial contract, derived in Section 3.5, turns out to be linear in  $E_t^i$ , the distribution of equity across entrepreneurs does not matter and exact aggregation is possible.<sup>26</sup> Hence, we anticipate results and note in analogy to the basic sector that the price level for the intermediate goods produced in the advanced sector is:

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

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

### 3.5 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.<sup>27</sup>

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.<sup>28</sup> In particular, the refinancing provisions determine the degree of insurance against idiosyncratic liquidity risk.<sup>29</sup> 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  $\xi_t$ . If the shock is met by appropriate refinancing to be provided by the intermediary, the firm can continue; otherwise the firm is liquidated.<sup>30</sup> 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.

<sup>26</sup>From now on, we will therefore drop the superscript  $i$ .

<sup>27</sup>Although the firm's production plan is conditional on the predetermined entrepreneurial equity position  $E_t$ , the firm problem itself is not dynamic because entrepreneurial asset accumulation proceeds mechanically and there is no intertemporal incentive provision.

<sup>28</sup>We assume that entrepreneurial self-financing is not possible; a sufficient condition for this to be the case is derived in the appendix.

<sup>29</sup>It is important to realize that the financial contract is negotiated after fresh cash  $\mathcal{J}_t$  has been injected into the economy. Consequently, the results of monetary policy that we will develop in the sequel do not stem from an implicit nominal rigidity. On the contrary, our concept of corporate liquidity is entirely real; what is affected by nominal fluctuations, however, is the price of such liquidity.

<sup>30</sup>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.

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  $0 < b < 1$ .<sup>31</sup> Finally, at *stage three*, the revenue from production accrues and payoffs are realized according to the rules stipulated in the financial contract. The financial intermediary engages in a continuum of contracts with advanced sector firms; hence, since liquidity risk is idiosyncratic, the intermediary is able to pool the risk inherent in the investments across individual firms' projects. As an implication, we can completely abstract from the effects of idiosyncratic uncertainty on the investor's evaluation of payoffs. Similarly, the entrepreneur who is exposed to her uninsured private equity risk is risk 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.

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

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

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

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

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

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<sup>31</sup>Note, however, that the specific value of  $b > 0$  will not matter as long as the contract to be derived below delivers an interior solution.

$$\Gamma_t(\xi_t)P_t^z\tilde{y}_t^z - \tau_t(\xi_t)C(W_t^z, R_t^z; \tilde{y}_t^z) \geq \Gamma_t(\xi_t)bP_t^z\tilde{y}_t^z \quad \forall \xi_t, \quad (12c)$$

where:

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

is firm level output conditional on survival and:

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

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:

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

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:

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

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.

### 3.6 Empirical implications

As an immediate consequence of optimal financial contracting as derived in Section 3.5 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*<sup>32</sup>, an increase in  $\tilde{R}_t$  leads to a lower cutoff  $\hat{\xi}_t^*$ :

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

which follows from total differentiation of condition (13).

Thus, quite intuitively, higher nominal interest rates  $\tilde{R}_t$  lead to smaller hedging against idiosyncratic liquidity shocks because the intermediary's participation constraint gets tighter in line with the increased costs of providing liquidity. In order to examine the effects of other changes in the economic environment on firms' liquidity demand, we establish two auxiliary results.

*First*, increased volatility of the liquidity shock distribution  $G(\cdot)$  in the sense of a mean-preserving spread implies a lower cutoff value  $\hat{\xi}_t^*$ ; formally  $\frac{\partial \hat{\xi}_t^*}{\partial \sigma_\xi} < 0$ .<sup>33</sup> 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  $\hat{\xi}_t^*$ :

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

<sup>32</sup>The claimed result obtains if, to a first approximation,  $\frac{MC_t^z(\cdot)}{P_t^z}$  remains constant. That is, the results derived in the following are valid from a partial equilibrium perspective; taking into account general equilibrium effects does not change the qualitative (sign) properties of the relevant derivatives. However, to obtain a closed-form solution, we have to determine a functional form of  $G(\xi)$ . It is shown in the appendix A.3 that the general equilibrium effect is negative if  $G' > 0$ .

<sup>33</sup>Variations in the standard deviation  $\sigma_\xi$  need to be restricted to mean-preserving spreads, the result then obtains by partial integration; compare Mas-Colell, Whinston and Green (1995), chapter 6.

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  $\frac{\partial \hat{\xi}_t^*}{\partial (MC_t^z/P_t^z)} > 0$ .<sup>34</sup> The reason for the poorer insurance of more profitable projects is the contracting trade-off underlying the choice of  $\hat{\xi}_t^*$ : While a more generous provision with liquidity has the advantage of withstanding larger shocks, it necessarily implies a lower stage one investment volume. Thus, for highly profitable projects, both contracting parties prefer to cut  $\hat{\xi}_t^*$  in order to expand the project size. Based on these results, we can derive two additional hypotheses relating to the sensitivity of specific firms (or industries) to fluctuations in the nominal interest rate.

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

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

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  $\hat{\xi}_t^*$ .

### 3.7 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:

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

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.<sup>35</sup> Note that

<sup>34</sup>This follows from total differentiation of condition (13), for given  $\tilde{R}_t$ .

<sup>35</sup>Note that terminated advanced projects are liquidated before the entrepreneur exerts any effort (moral hazard problem). Thus, it is quite natural to assume that these *failed* projects do not cause any knowledge externality.

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.<sup>36</sup> 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 monetary policy.

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.

### 3.8 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:

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

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

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

where  $mg^*$  is the steady state level of money growth, which together with the economy's exogenous (balanced) growth rate  $\gamma$  determines the rate of inflation prevailing in steady state.

### 3.9 Equilibrium

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

**Definition 1 (Competitive Equilibrium)** *Given initial conditions  $\{k_0, z_0, A_0, M_0\}$  and realizations 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  $\{c_t, l_t^k, l_t^z, \bar{L}, \bar{K}, y_t^k, y_t^z, y_t\}_{t=0}^\infty$  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);*

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<sup>36</sup>Compare Romer (1990) or Aghion and Howitt (1992).

2. *entrepreneurs follow their behavioral rules and the financial intermediary breaks even;*
3. *aggregation across agents and sectors as well as among the entrepreneurs obtains, i.e. for a generic variable  $v_t^{E,i}$  belonging to the allocation to entrepreneurs:  $\int_i v_t^{E,i} di = v_t^E$ ;*
4. *the financial market as well as the markets for final goods, intermediate goods and factor inputs clear.*

A set of useful-to-understand aggregate relations characterizing a competitive equilibrium is derived in Appendix A.2. Furthermore, 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.

## 4 Long-run balanced growth path

In this section, we solve our model for a long-run balanced growth path, which comprises a constant equilibrium growth rate of all endogenous aggregate variables. Hence, the ratio of capital and labor in the two intermediate sectors  $(\frac{z_t}{k_t}, \frac{l_t^z}{l_t^k})$  must be constant in a long-run balanced growth path. Since technological progress is the only source of endogenous growth in this model, the equilibrium growth rate is determined by the law of motion in (18a):

$$\gamma = \frac{\mathcal{T}_{t+1}}{\mathcal{T}_t} - 1 = \epsilon \int_0^1 G(\hat{\xi}_t^*) \tilde{y}_{t,i}^z di \quad (20)$$

It follows that we need to solve for the equilibrium level of successful realizations of advanced projects in order to analyze the determinants of the long-run balanced growth path. In fact, (20) implies that the direct effect of corporate liquidity  $\hat{\xi}_t^*$  (the nominal interest rate,  $\tilde{R}$ ) on the growth rate is positive (negative). Thus, for given investments  $\tilde{y}_t^z$ , an increase in corporate liquidity augments the number of advanced projects that are successfully continued after the liquidity shock has realized - relatively more advanced projects survive. It remains to show that  $\hat{\xi}_t^*$  also reduces the scale of investments in the advanced technology  $\tilde{y}_t^z$ .

We know that rental rates and wages in both sectors must be equal in expectations which must be satisfied along a balanced growth path. From (6)-(11), (25) and the equalization of wages ( $W_t$ ) and rental rates ( $R_t$ ) in the two intermediate sectors, we can derive the equilibrium factor proportions:

$$\frac{z}{l_t^z} = \frac{k_t}{l_t^k} = \frac{\alpha}{1 - \alpha} \frac{W_t}{R_t} \quad (21)$$

Note that in (21) we abstract from directed technical change and assume that  $\alpha^z = \alpha^k$ . It follows from (13) that the associated total costs in the advanced sector, which accrue when an output level of  $\tilde{y}_t^z$  is targeted in case of survival, amount to  $\widetilde{MC}^z = \frac{A}{V} MC^k$ . If we substitute (25) into (21) and make use of  $\widetilde{MC}^z = \frac{A}{V} MC^k$  and  $MC^k = P^k$ , we obtain the constant ratio of the total costs associated with  $\tilde{y}_t^z$  to the total costs in the basic sector:

$$\begin{aligned} \frac{\widetilde{MC}^z \widetilde{y}_t^z}{P^k y_t^k} &= 1 \\ \Rightarrow \frac{y_t^z}{y_t^k} &= \frac{V}{A} G(\hat{\xi}_t^*), \end{aligned} \quad (22)$$

where  $y_t^z = \widetilde{y}_t^z G(\hat{\xi}_t^*)$ . 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 compute the total differential of (22), we obtain the total derivative of the intermediate output ratio with respect to changes in corporate liquidity:

$$\frac{d\left(\frac{y_t^z}{y_t^k}\right)}{d\hat{\xi}_t^*} = \frac{V}{A} g(\hat{\xi}_t^*) > 0 \quad (23)$$

Hence, the equilibrium ratio of investments in the advanced relative to the basic sector is increasing in corporate liquidity holdings ( $\hat{\xi}_t^*$ ). It follows from  $\mathcal{H}1$  that this ratio is decreasing in the nominal interest rate  $\tilde{R}_t$ . That is, less resources are devoted to the advanced project if the cost of liquidity holdings increases. Finally, we know that the aggregated output level ( $y_t$ ) is decreasing in the financial rate ( $\tilde{R}_t$ ) since the rental rate of capital ( $R_t$ ) increases in  $\tilde{R}_t$ .<sup>37</sup> Since the nominal interest rate  $\tilde{R}_t$  reduces both, the ratio ( $\frac{y_t^z}{y_t^k}$ ) and the aggregate output level, it also reduces investments in the advanced project ( $\frac{\partial y_t^z}{\partial \tilde{R}_t} < 0$ ).

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. Thus, an increase in the amount of corporate liquidity holdings enhances economic growth ( $\frac{\partial \gamma}{\partial \hat{\xi}_t^*} > 0$ ). It follows from ( $\mathcal{H}1$ ) that the long-run balanced growth rate is decreasing in the nominal interest rate ( $\tilde{R}_t$ ) and hence in the (expected) level of inflation. In fact, each level of the nominal interest rate (trend inflation) implies a different long-run balanced growth rate:  $\gamma = \gamma(\tilde{R}_t)$ . Intuitively, this link between (expected) inflation and TFP-growth in the case of incomplete financial markets is due to the allowance for firm-level heterogenous investment projects with respect to a risk-productivity tradeoff in our framework.

- $\mathcal{I}1$ : *Ceteris paribus*, an increase in  $\tilde{R}_t$  leads to a lower long-run balanced growth rate  $\gamma$  by reducing the liquidity holdings of firms in equilibrium:

$$\frac{\partial \gamma}{\partial \tilde{R}_t} = \frac{\partial \gamma}{\partial \hat{\xi}_t^*} \frac{\partial \hat{\xi}_t^*}{\partial \tilde{R}_t} < 0 \quad (24)$$

which follows from the partial derivative (20) with respect to  $\hat{\xi}_t^*$  and  $\mathcal{H}1$ .

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<sup>37</sup>Rewriting the second Euler condition (3) for the case of a CRRA utility function ( $U(c_i) = \frac{c_i^{1-\rho}-1}{1-\rho}$ ), we get:  $R_t = \tilde{R} \left( \frac{1+\gamma}{\beta} - (1-\delta) \right)$ . For  $\epsilon$  small enough, such that the direct effect of  $\tilde{R}_t$  on  $R_t$  outweighs the indirect via a decrease in  $\gamma$ , we know that  $R_t$  is strictly increasing in  $\tilde{R}_t$ .

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.

Moreover, (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:  $\int_0^{\hat{\xi}_t^*} G(\xi)d\xi = 1$ . 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.

## 5 Empirical analysis

Section 2 illustrates the empirical robustness of a negative causal impact running from inflation to long-run TFP-growth and hence the quantitative importance of  $\mathcal{I}1$ . Still, we can not be sure if this macroeconomic outcome is indeed generated by our specific microeconomic framework. Therefore, in this section, we apply microeconomic data to identify the quantitative importance of our particular monetary transmission channel which is based on the constraint optimal financial contract between a firm and the financial intermediary. First, we employ sectoral data to reveal systematic variations of the inflation- TFP-growth nexus with the volatility and profitability of a specific sector ( $\mathcal{H}2, \mathcal{H}3$ ). Second, we refer to firm level data to inquire the impact of inflation on firm-level liquidity holdings ( $\mathcal{H}1$ ) and corporate investment portfolio decisions.

### 5.1 Sectoral level

In this section, we test the model-specific empirical implications  $\mathcal{H}2$  and  $\mathcal{H}3$ . That is, we apply 3-digit industry level data to explore if the sensitivity of sectoral productivity with respect to (aggregate) inflation is (i) higher in more volatile sectors ( $\mathcal{H}2$ ) and (ii) higher in sectors that featured a higher average productivity growth in our sample ( $\mathcal{H}3$ ).<sup>38</sup> Hence, firms operating in more volatile and profitable sectors are expected to adjust their investment portfolio more sensitive to changes in inflation.<sup>39</sup> The productivity of different sectors is measured by the amount of value added from the UNIDO industry database. The data are available for 53 countries and 29 industries from 1980-2000. We employ the Arellano and Bond (1991) estimator and control for the aggregated institutional and financial variables. A measure of the volatility of each sector is taken from Koren and Tenreyro (2005) who conduct a variance decomposition

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<sup>38</sup>We know from (26) that, ceteris paribus, an increase in advanced sector productivity ( $V_t$ ) results in a higher profitability as defined in  $\mathcal{H}3$ .

<sup>39</sup>Note that we refer to changes in investment portfolios within sectors instead of across sectors. Hence, an investor shifts investments to alternative more secure projects within the same sector if insurance against idiosyncratic risk becomes more expensive. A shift of investment projects across sectors appears to be negligible since only large diversified firms may have the opportunity to adjust their investments across different industries.

analysis to compute the average standard deviation (across countries and time periods) of innovations to the growth rate of value added per worker (from the UNIDO industry database) for each sector. Moreover, we approximate the profitability of each industry by the average growth rate of value added for each sector. The rankings of the industries with respect to volatility and average productivity growth are reported in Table 1. The correlation coefficient between these two rankings is positive (0.03) and significantly different from zero on a 1% level according to Spearman’s rank correlation test.<sup>40</sup> Hence, an independence of both rankings is rejected confirming that more volatile sectors are characterized by higher average productivity growth. In order to test  $\mathcal{H}2$  and  $\mathcal{H}3$ , we divide the sample according to the median, the first and the fourth quartile of the volatility measure as well as the average sectoral growth rate of value added.<sup>41</sup>

In Table 3, we divide the sample into sectors that exhibit an average volatility above and below the median. The first column reveals that inflation reduces the growth rate in value added in more volatile sectors. The result is significant on a 1% level and robust to the inclusion of the financial control variables. The financial variables themselves and the private investment share do not influence productivity growth. In contrast, inflation has no impact on productivity growth in the sectors that feature an average volatility of value added below the median. In column three and four, we focus on the most volatile sectors (first quartile). Again, inflation significantly reduces productivity growth in this sub-sample independent of the inclusion of financial controls. Contrarily, the coefficient of inflation is even positive but not significant in the least volatile sectors (4. quartile). These results confirm the predictions of our theoretical model: investors in more volatile sectors respond more strongly to changes in inflation (by adjusting their nominal asset holdings).<sup>42</sup> In contrast, this portfolio adjustment effect is, on average, not observable in more secure sectors.

The last four columns of Table 3 report the relation between inflation and productivity growth in sub-samples that are separated according to the average growth rate of value added. Inflation deters productivity growth in sectors that exhibit an average productivity growth above the median. In contrast, it does not affect its growth rate in sectors below the median. However, the results are different if we concentrate on the sectors in the first and fourth quartile: Inflation tends to reduce growth in value added in both groups. Summing up, apart from that latter group, the sectoral results confirm the empirical implications  $\mathcal{H}2$  (and  $\mathcal{H}3$ ) of our specific monetary transmission mechanism.

## 5.2 Firm level

Microeconomic data on firm-level behavior allow for the most straightforward test of our specific theoretical mechanism. That is, our model predicts that firms react to an increase in inflation (the nominal interest rate) by reducing their liquidity holdings (insurance) against liquidity shocks from superior investments and by shifting their portfolio towards more secure investments ( $\mathcal{H}1$ ). Thus, we expect that an increase in corporate liquidity holdings augments

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<sup>40</sup>The correlation coefficient amounts to .23 (s.e.=0.03) if we exclusively focus on the sub-sample of 28 U.S. industries.

<sup>41</sup>The average per sector is computed over time and across countries.

<sup>42</sup>We find the same systematic qualitative pattern in the data if we exclusively focus on the sub-set of 28 U.S. industries. The results are available from the authors upon request.

investments in superior technologies. In turn, an increase in inflation (the nominal interest rate) is expected to reduce corporate liquidity holdings and hence also corporate investments in superior technologies. In order to test these hypotheses we employ U.S.- firm-level data based on 5-year averages from the Compustat database. The data relate to the balance sheets of US nonfinancial firms and cover the time period 1970-2000. Specifically, 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 corporate interest rate expenses and the amount of long-term debt. The R&D investments per firm are used as a proxy for investments in superior technologies.<sup>43</sup> The amount of cash and marketable securities reflects the overall corporate liquidity holdings and the amount of total assets the size of a firm. All variables are measured in millions of dollars. In addition, we use the rate of inflation based on the consumer price index in the U.S. to investigate the effect of these macroeconomic variables on firm level liquidity and investment portfolios.<sup>44</sup>

In this context, we point out the empirical evidence provided by Opler et al. (1999) in favor of ( $\mathcal{H}1$ ) based on yearly U.S.- firm-level data from 1970-1993. The authors proxy a firm's investment opportunities by its market-to-book value and/or its expenses for R&D, respectively; the risk associated with a firm's cash flow is measured by the standard deviation of the cash flows. The study finds that the value of liquid assets (cash and marketable securities) relative to total assets amounts to 18% on average in US firms. Furthermore, they show that US firms with higher growth opportunities and riskier cash flows 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, but risky 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.

Overall, we have an unbalanced panel consisting of over 2000 firms and six time observations. We employ the GMM difference estimator following Arellano and Bond (1991). In all estimations, we employ heteroscedasticity- and serial correlation robust standards errors. Finally, note that the mix of macro- and microeconomic data allows for an 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.

The first column of Table 4 reveal a negative correlation between inflation and firm-level R&D expenses after controlling for firm-size, the amount of long-term debt and corporate interest expenses. The corresponding coefficient is significant on a 5% level. This negative correlation declines significantly if we additionally control for liquidity holdings per firm. 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. The LSDV estimator broadly confirms this correlation pattern in the data. Yet, the results are biased since we include a lagged dependent variable. Therefore, we report the results of our preferred estimation

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<sup>43</sup>If we interpret investments in superior technologies as investments in new technologies, while investments in less productive projects reflect production with conventional technologies, R&D expenses are the most appropriate candidate for an approximation of advanced investments projects.

<sup>44</sup>We stress that our results based on the LSDV and the GMM difference estimator do not suffer from an aggregation bias, as outlined by Moulton (1990), since we employ serial correlation robust standard errors to avoid within-group correlation.

specification in columns five to six. Accordingly, inflation substantially reduces firm-level R&D expenses: a 1% increase in inflation depresses firm-level R&D expenses on average by 1.9 million \$ after controlling for variations in firm-size, the amount of long-term debt and corporate interest expenses. The corresponding coefficient is significant on a 1% level. This distorting impact declines on average by 64% if we additionally control for liquidity holdings per firm. 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  $\mathcal{I}1$ . Moreover, we reject the presence of second order autocorrelation and the Hansen test of overidentifying restrictions never rejects the validity of the instruments. Hence, the estimation specification appears to be well specified.<sup>45</sup> Finally, the last two columns of Table 4 report, in accordance with  $\mathcal{H}1$ , that inflation reduces corporate liquidity holdings substantially. Accordingly, a 1% increase in inflation depresses corporate liquidity holdings on average by 5 million \$. The corresponding coefficient is significant on a 1% level if we employ the GMM difference estimator.

Summing up, the firm-level results show that inflation has a negative impact on firm-level investments in superior technologies. However, this effect disappears if we correctly control for corporate holdings of cash and marketable securities. Thus, the impact of inflation on firm-level compositional investments decisions is (at least partly) due to variations in corporate liquidity holdings. This empirical result directly approves the microeconomic mechanism underlying our theoretical derivations of a negative aggregate relation between inflation and long-run TFP-growth.

## 6 Concluding remarks

The present paper combines elements of the growth and business cycle literature: it considers short-run monetary policy shocks as well as their interaction with a specific financial markets friction, but at the same time endogenizes the productivity process via an endogenous technology choice which is catalyzed by this friction. We demonstrate in the context of an endogenous growth model with financial market frictions that short-run nominal fluctuations reduce long-run productivity growth. 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 connection 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. More precisely, we detect at the sectoral 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

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<sup>45</sup>Inflation is considered as an exogenous variable (see above). The microeconomic variables are considered as (potentially) endogenous.

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, which are a novel aspect of our model, lead to the key insight: the short-run interplay between monetary policy, 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 (-growth) explain roughly 2/3 of cross-country income fluctuations, differences in trend inflation across countries represent an important tool to account for international income varieties. 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. Moreover, our findings justify supportive public financing programs for R&D intensive (small and medium) enterprises.

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

$$z_t = \frac{\alpha^z P_t^z \tilde{y}_t^z}{R_t^z} \quad \text{and} \quad l_t^z = \frac{(1 - \alpha^z P_t^z \tilde{y}_t^z)}{W_t^z} \quad (25)$$

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

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

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

**First best - the socially optimal contract:** Let us first look at the first best contract where  $b = 0$  such that the entrepreneurial moral hazard problem plays no role (but liquidity is scarce and has an opportunity cost  $\tilde{R}_t$ ). The questions asked here are, what is the maximum overall return on investment, and how does the corresponding socially optimal contract look like? Suppose for the moment a binding participation constraint for the investor; indeed, we will later verify that this is the case in a well-specified problem.<sup>46</sup> 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:

$$\Pi_t^F(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t) MC_t^z(\cdot) \tilde{y}_t^z, \quad (26a)$$

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<sup>46</sup>By well-specified, we mean (i) that there is no self-financing by the firms, and (ii) that the solution to the constrained-optimal contract features a finite investment level.

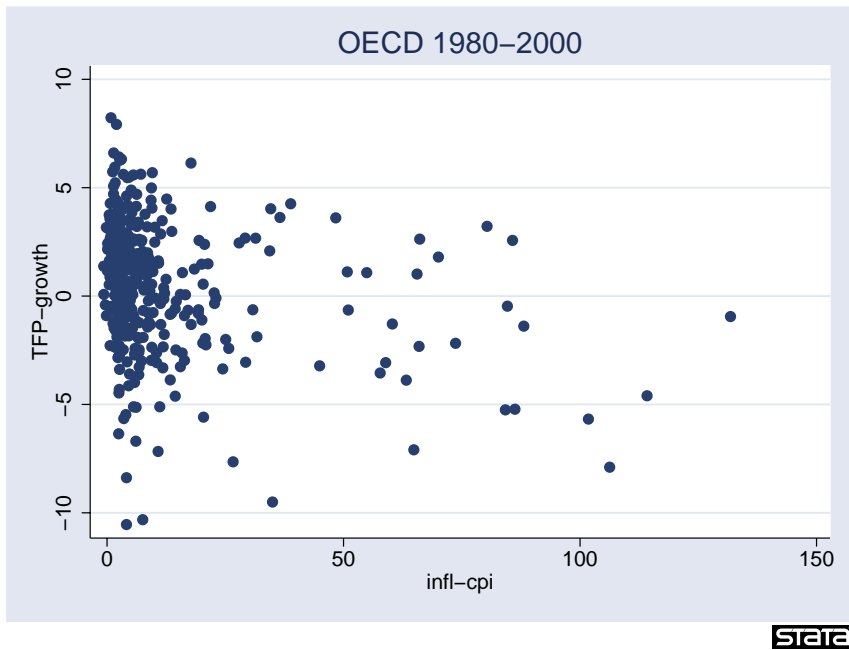


Figure 1: Scatter-plot: Panel of 22 OECD countries 1980-2000

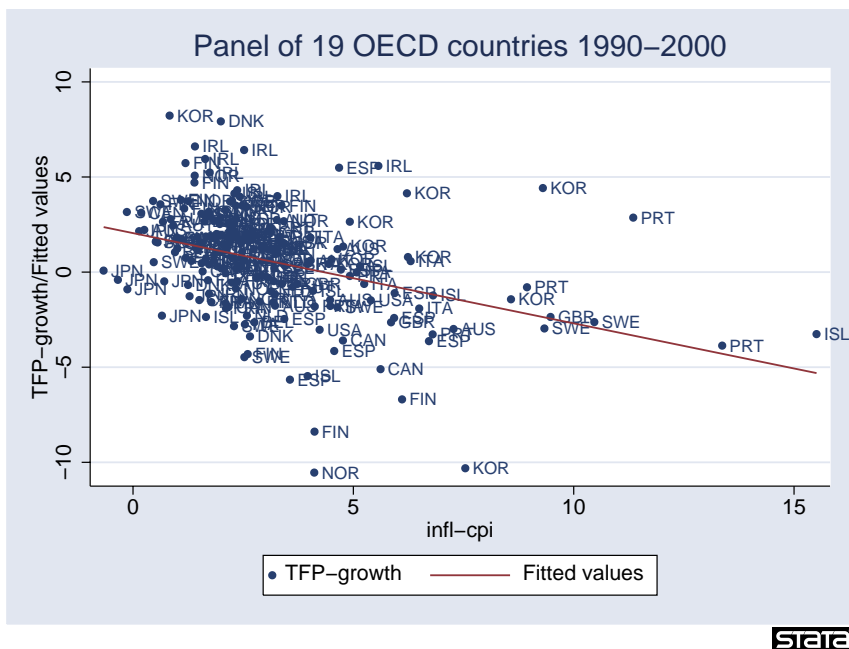


Figure 2: Scatter-plot: Panel of 19 OECD countries 1990-2000

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Table 1: Sectoral volatility (Koren and Tenreyro, 2005), average value added per sector

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Industries	volatility	ranking	aver. value added	ranking
Beverages	0.0570	19	7.99E+08	13
Fabricated metal products	0.0610	17	1.95E+09	5
Food products	0.0570	19	2.71E+09	4
Footwear, except rubber or plastic	0.0720	10	1.54E+08	25
Furniture, except metal	0.0650	16	4.26E+08	21
Glass and products	0.0510	22	2.84E+08	23
Industrial chemicals	0.0700	11	1.75E+09	6
Iron and Steel	0.1410	1	1.63E+09	7
Leather products	0.0870	6	1.44E+08	26
Machinery, electric	0.0500	25	2.93E+09	3
Machinery, except electrical	0.0610	17	3.32E+09	1
Misc. Petroleum and coal products	0.0700	11	8.41E+07	27
Non-ferrous metals	0.1410	1	5.39E+08	18
Other manufacturing products	0.0700	11	4.39E+08	20
Other non-metallic mineral products	0.0510	22	9.47E+08	11
Paper and products	0.1080	3	9.53E+08	10
Petroleum refineries	0.0700	11	9.39E+08	12
Plastic products	0.0750	9	6.46E+08	16
Pottery, china, earthenware	0.0510	22	1.74E+08	24
Printing and publishing	0.0460	27	1.38E+09	9
Professional & scientific equipment	0.0660	15	6.60E+08	15
Rubber products	0.0800	8	4.26E+08	22
Textiles	0.0890	5	1.46E+09	8
Tobacco	0.0570	19	5.14E+08	19
Transport equipment	0.0850	7	2.95E+09	2
Wearing apparel, except footwear	0.0500	25	7.85E+08	14
Wood products, except furniture	0.0900	4	5.92E+08	17

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The correlation coefficient between volatility and average growth of value added is positive 0.03 (.0057) and significant on a 1% level (rank correlation test); the correlation coefficient amounts to 0.23 (.0299) for the sub-sample of 28 U.S. industries.

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*** (-7.33)	-.0009*** (-4.17)	-.0020*** (-2.74)	-.0016** (-2.44)	-.0022*** (-2.96)		-.0059** (-2.05)	-.0646*** (-2.85)
infl-vol						-.0009** (-2.01)	.0026* (1.66)	
credit	.2479 (.54)	-.7932 (-.93)	.7770 (.69)	-.5247 (-.46)	.8965 (.81)	.7517 (.66)	.0139 (.01)	.4846 (.58)
trade	.0021 (.82)	.0154 (.96)	.0066 (1.05)	.0027 (.35)	.0047 (.87)	.0079 (1.22)	.0076 (1.38)	
ki				.1309*** (2.21)				
ppr	.3130*** (3.58)	.1759 (1.26)	.4452*** (2.94)	.3656** (2.53)	.4182** (2.81)	.4294** (2.92)	.4779*** (3.32)	-.2293* (-1.71)
kg	-.0113 (-.59)	-.0687 (-.79)	-.0243 (-.87)	-.0145 (-.54)	-.0214 (-.81)	-.0257 (-.95)	-.0145 (-.54)	-.0606 (-1.07)
tot	-.0066 (-.87)	-.0013 (-.12)	-.0055 (-.59)	-.0164 (-1.54)	-.0058 (-.66)	-.0062 (-.67)	-.0047 (-.51)	.2247** (2.18)
lag dep. var.	-.0049*** (-3.24)	-.0229*** (-5.28)	-.0180*** (-5.53)	-.0183*** (-5.07)	-.0162*** (-5.52)	-.0171*** (-5.41)	-.0151*** (-5.65)	-.6202*** (-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							
	vol>med	vol≤med	vol>1. qua	vol<3. qua	av>med	av<med	av>1.qua	av<3.qua
infl	-.0074*** (-4.63)	.0240 (.81)	-.0073*** (-4.56)	.0438 (0.88)	-.0058** (-2.13)	.0254 (.48)	-.0052 (-.85)	-.0064*** (-4.53)
credit	.3332 (1.08)	2.15 (1.14)	-.0163 (-.12)	3.52 (1.20)	.6827 (1.66)	1.88 (1.02)	1.01 (1.33)	.0238 (.19)
smtra	.2111 (1.52)	-.4035 (-.68)	.0308 (.62)	-.5175 (-.54)	.3967 (1.91)	.0363 (.12)	.7512 (1.59)	.0389 (.79)
fin	-.0776 (-.77)	-.2109 (-.73)	.0483 (.72)	-.5061 (-.93)	-.1265 (-1.22)	-.0915 (-.63)	-.0616 (-.23)	.0371 (.64)
inv-share	-.0003 (-.05)	.1360 (.89)	.0090** (2.13)	.2361 (.94)	-.0209 (-1.27)	.1424 (1.00)	-.0126 (-.55)	.0047 (1.21)
Instit. controls	yes	yes	yes	yes	yes	yes	yes	yes
Per./Obs.	19/10444	19/10661	19/4711	19/6874	19/10466	19/10639	19/5179	19/6108
1. auto-cor.	0.082	0.268	0.059	0.267	0.264	0.299	0.289	0.047
2. auto-cor.	0.085	0.473	0.264	0.478	0.500	0.484	0.555	0.205
Sargan-test	-	-	-	-	-	-	-	-

Additional institutional controls (not reported): government share as % of GDP, amount of trade in goods as % of GDP, terms of trade, index of overall property rights. 1980-2000 yearly data. Always include a constant, heteroscedasticity robust s.e.; t-statistics in parenthesis. \*\*\*, \*\*, \* significant at 1%, 5%, 10%. GMM system estimator in all specifications.

Table 4: US firm-level data: 5-year-averages: Inflation, liquidity holdings and R&D expenses

	R&D expenses per firm						Corporate liquidity	
	OLS	OLS	LSDV	LSDV	GMM-dif	GMM-dif	OLS	GMM-dif
inflation	-.4282** (-2.26)	-.2910 (-1.60)	-1.81*** (-3.06)	-1.95*** (-3.73)	-1.93*** (-3.27)	-.7018 (-.92)	-1.18* (-1.79)	-4.95*** (-2.84)
corp. liquidity		.0700*** (4.14)		.1078*** (5.77)		.2937*** (3.55)		
assets	.0017 (1.33)	-.0021 (-1.21)	.0085** (2.28)	.0060** (2.53)	.0028 (.32)	.0121** (2.05)	.0226** (2.37)	.0488*** (2.60)
interest exp.	.1878*** (3.70)	.1432 (1.56)	.3768*** (3.09)	.3407*** (4.17)	.4137 (1.40)	.7653*** (2.83)	.2608 (1.04)	-1.08 (-1.20)
long-term debt	-.0170** (-2.07)	-.0049 (-.55)	-.0518*** (-2.71)	-.0490*** (-3.43)	-.0146 (-.31)	-.1228*** (-3.58)	-.0429 (-1.11)	.0407 (.34)
lag-dep.-var.	1.23*** (24.34)	1.13*** (20.45)	.9543*** (10.93)	.7871*** (9.02)	.7759*** (6.31)	.3339** (2.49)	.9322*** (8.84)	.3199** (2.07)
Per./Obs.	6/10812	6/10811	6/10812	6/10811	4/5515	4/5514	6/10811	4/5514
1. auto-cor.	-	-	-	-	.586	.413	-	.647
2. auto-cor.	-	-	-	-	.176	.840	-	.669
Hansen-test	-	-	-	-	.661	.775	-	.307

5-year-averages: 1970-2000. heteroscedasticity-robust s.e. t-statistics in parenthesis. \*\*\*, \*\*, \* significant at 1%, 5%, 10%. LSDV refers to the least square dummy estimator, whereby we control for firm fixed effects and cluster errors at the firm level.

where:

$$\lambda_t(\hat{\xi}_t) \equiv \left[ \int_0^{\hat{\xi}_t} \frac{P_t^z}{MC_t^z(\cdot)} \left(1 - \xi_t \tilde{R}_t\right) dG(\xi_t) - 1 \right] \quad (26b)$$

In definition (26b),  $\lambda_t(\hat{\xi}_t)$  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 (26a), it is clear that the entrepreneur is the residual claimant and receives the full social surplus from the project.

**Second best - entrepreneurial moral hazard:** Now consider the case where  $b > 0$ . First of all note that general equilibrium considerations imply that the marginal net social return under both the first and the second best solution must be positive.<sup>47</sup> Then, given a positive value for  $\lambda_t(\hat{\xi}_t)$ , the entrepreneur will seek to maximize  $\Pi_t^F(\hat{\xi}_t)$  by choosing the maximum investment volume  $MC_t^z(\cdot)\tilde{y}_t^z$  that still guarantees investor participation. But from (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:

$$\tau_t(\xi_t) = \frac{\Gamma_t(\xi_t)(1-b)P_t^z\tilde{y}_t^z}{MC_t^z(\cdot)\tilde{y}_t^z} \quad (27)$$

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

$$\left[ 1 - \int \Gamma(\xi_t) \left( (1-b) - \xi_t \tilde{R}_t \right) \frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t) \right] MC_t^z(\cdot)\tilde{y}_t^z = E_t \quad (28)$$

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 (28) implies that, given some  $E_t > 0$ , the expected (subject to idiosyncratic liquidity shocks) marginal return on outside investment is strictly smaller than one.<sup>48</sup>

<sup>47</sup>To see this, suppose to the contrary that  $\lambda(\hat{\xi}_t^{FB}) \leq 0$  such that the optimal contract would prescribe  $z_t = l_t^z = 0$ , i.e. zero investment for any level of entrepreneurial equity  $E_t$ . However, this implies  $\tilde{y}_t^z = 0$  which contradicts a general equilibrium with positive consumption and investment, and the price of the advanced intermediate good would adjust such as to guarantee a positive marginal net social return. By the same token, the second best solution must also involve a cutoff rule  $\hat{\xi}_t$  with positive marginal net social return.

<sup>48</sup>Indeed, if this was not the case, investment would be self-financing and there would be no demand for

Solving equation (28) for the maximum investment volume conditional on a given cutoff value  $\hat{\xi}_t$ , allows to write the firm's investment capacity as:

$$MC_t^z(\cdot)\tilde{y}_t^z = \mu_t(\hat{\xi}_t)E_t, \quad (29a)$$

where:

$$\mu_t(\hat{\xi}_t) \equiv \frac{1}{1 - \int_0^{\hat{\xi}_t} \left( (1-b) - \xi_t \tilde{R}_t \right) \frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t)} \quad (29b)$$

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 (28). Finally, using (26a) and (29a), the entrepreneur's expected net payoff becomes:

$$\Pi_t^F(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t)\mu_t(\hat{\xi}_t)E_t \quad (30)$$

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 (30). 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 (26b) and (29b) into (30), it is straightforward to show that the optimal continuation value  $\hat{\xi}_t^*$  can be found as the solution to the following problem:

$$\min_{\hat{\xi}_t} \frac{\tilde{R}_t \int_0^{\hat{\xi}_t} \xi_t dG(\xi_t) + \frac{MC_t^z(\cdot)}{P_t^z}}{G(\hat{\xi}_t)} \quad (31)$$

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

$$\int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t = \frac{MC_t^z(\cdot)}{P_t^z} \frac{1}{\tilde{R}_t} \quad (32)$$

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:

$$\Pi_t^F(\hat{\xi}_t^*) = \frac{\frac{1}{\bar{R}_t} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \frac{(1-b)}{\bar{R}_t}} E_t = \frac{\hat{\xi}_t^{FB} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \hat{\xi}_t^0} E_t \quad (33)$$

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:

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

**Implementation and aggregate liquidity demand:** In order to cover liquidity shocks up to the second best cutoff  $\hat{\xi}_t^*$ , it is necessary that outside investors commit funds at the initial contracting stage (*stage one*). The reason is that, by issuing corporate claims at the interim stage (*stage two*), it is not possible to raise enough funds because the entrepreneurial commitment problem limits the maximum return pledgeable to outside investors at  $\hat{\xi}_t^0 < \hat{\xi}_t^*$ . It is then a natural question to ask how the second best policy can actually be implemented at the initial contracting stage; moreover, in view of our modelling hypothesis that an economy's physical investment portfolio is affected by the degree to which firms can insure their activities by means of holding corporate liquidity, there arises the related question of whether there is a second best policy that features firms (rather than the intermediary) holding liquidity.

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

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

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

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

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

Now, drawing on Holmstrom and Tirole (1998), we turn to the institutional details supporting the implementation of the second best policy derived in Section 3.5. One possibility is to have the financial intermediary initially extend the amount  $MC_t^z(\cdot) \tilde{y}_t^z - E_t$  to the entrepreneur together with an *irrevocable line of credit* of maximum size  $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$  to be drawn from as needed at the interim stage. Given our assumptions on the details of the moral hazard problem which does not envisage distraction of resources on the part of the entrepreneur, this

line of credit implements the second best solution as long as the credit line, irrespective of the amount  $\xi_t P_t^z \tilde{y}_t^z \leq \hat{\xi}_t^* P_t^z \tilde{y}_t^z$  of liquidity actually requested, is provided free of charge. Since the firms' liquidity shocks are independent, the aggregate amount of resources needed to cover the advanced sector's refinancing needs at the interim stage is then given by  $D_t^*$ . At the level of an individual advanced sector firm, an alternative would be via a *liquidity covenant* which involves the financial intermediary initially extending the amount  $[1 + (P_t^z / MC_t^z(\cdot)) \hat{\xi}_t^*] MC_t^z(\cdot) \tilde{y}_t^z - E_t$  to the entrepreneur, whereby the requirement is imposed that the amount  $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$  is not sunk in the project but kept in the form of readily marketable assets. However, at the aggregate level across all advanced sector firms, implementation of the second best policy via liquidity covenants is seen to require strictly more resources  $\bar{D}_t > D_t^*$  because liquidity is kept separately at each firm, thus forgoing the potential to pool liquidity across firms.<sup>49</sup>

Given our empirical interest, the question arises whether there is a second best policy that features firms (rather than the intermediary) holding liquidity. We now give an example for such a policy. For that purpose, first define a number  $\check{\xi}_t$  which is implicitly given by  $D_t^* = \check{\xi}_t P_t^z \tilde{y}_t^z$ ; then, a policy of the desired kind is constructed as follows: At stage one, the intermediary extends the amount  $[1 + (P_t^z / MC_t^z(\cdot)) \check{\xi}_t] MC_t^z(\cdot) \tilde{y}_t^z - E_t$  to the entrepreneur. The financial contract further stipulates that the amount  $\check{\xi}_t P_t^z \tilde{y}_t^z$  must be held in the form of liquid assets. The firm will then invest up to the maximum admissible scale  $MC_t^z(\cdot) \tilde{y}_t^z - E_t$  and deposit its liquid assets with the intermediary (at zero interest). Now, at stage two, when hit by a liquidity shock  $\xi_t$ , the firm must first use up its own asset position of  $\check{\xi}_t P_t^z \tilde{y}_t^z$ ; only then can it approach the intermediary for additional funds, which the latter will residually provide up to the second best quantity  $\hat{\xi}_t^* P_t^z \tilde{y}_t^z$ . The intermediary is able to provide this liquidity by calling idle funds from those firms who receive shocks  $\xi_t < \check{\xi}_t$ . Obviously, this policy replicates the second best in terms of both the initial investment scale and the cutoff  $\hat{\xi}_t^*$ . Thus, it only remains to check whether above arrangement is feasible, which is the case since, from the definition of  $\check{\xi}_t$ , the supply of and demand for liquidity are equal at the aggregate level:  $P_t^z \tilde{y}_t^z \check{\xi}_t = D_t^* = P_t^z \tilde{y}_t^z \int_0^{\check{\xi}_t} \xi_t g(\xi_t) d\xi_t$ . 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:

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<sup>49</sup>In the benchmark section of their paper which features an exogenous supply of liquidity, Holmstrom and Tirole (1998) establish equivalence of the two methods of providing liquidity. This result stems from the fact that their economy allows for a technology ("cash") to transfer wealth across the stages of the financial contracting problem and the additional assumption that "cash" is not scarce. Conversely, in our economy "cash" is available, but its (limited) supply is determined in general equilibrium via households' financial deposits and monetary policy. Importantly then, liquidity is costly (it has a price  $\tilde{R}_t > 1$ ), and agents have an incentive to economize on its usage. The consequence is that intermediated credit lines and liquidity holdings on behalf of the firms are no longer equivalent.

$$Q_t + (1 - \eta)A_t = P_t c_t, \quad (35)$$

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

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

where we note that  $\Upsilon_t = D_t + E_t$ . This relation stipulates that, at the end of any given period, the nominal resources  $D_t + E_t$  lost due to liquidity shocks are 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 (35), one obtains:

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

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

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

where  $E_t = \eta A_t$ . In order to derive a convenient expression for the evolution of aggregate wealth, we add equations (36) and (38) and employ the zero-profit condition mentioned above as well as condition (4) to obtain:

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

which gives immediately rise to a modified quantity relation:

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

Again, this equation allows for an intuitive interpretation, namely that the contemporaneous price level  $P_t$  is determined as the ratio of nominal resources channelled through the goods market to aggregate output.<sup>50</sup>

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<sup>50</sup>To see this, note that the agents' end-of-period wealth  $M_{t+1} + A_{t+1}$  is effectively generated via firm profits whose generation requires transactions on the goods market; from this amount, the nominal resources which are absorbed by liquidity needs and later redistributed to the household sector must be deduced.

### A.3 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  $\xi$ .

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:

$$G(\hat{\xi}_t^*) = \frac{1-\zeta}{\zeta} \left(\frac{A}{V}\right)^{1-\rho} \left(\tilde{R}_t \int 0 \hat{\xi}_t^* G(\xi) d\xi\right)^\rho \quad (41)$$

Taking the total derivative of (42) 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:

$$\frac{d\hat{\xi}_t^*}{d\tilde{R}_t} = \frac{\tilde{R}_t}{\hat{\xi}_t^*} \frac{\rho\phi}{1-\rho(1+\phi)} < 0 \quad (42)$$

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

### A.4 Data and methodology

We apply dynamic panel estimations following Arellano and Bond (1991) and Bond and Blundell (1998).<sup>51</sup> These procedures allow to gain inspection of causality relying on internal instruments as suggested by Arellano and Bover (1995) and provide a test for the validity of the internal instruments.<sup>52</sup> The key observation is that the (second or larger) lag of an endogenous variable is a valid internal instrument in the absence of second order autocorrelation. The estimators are based on the general method of moments (GMM) and are constructed to yield consistent estimates in dynamic panels. In particular, Arellano and Bond (1991) estimate a dynamic panel data model in first differences and apply appropriate lagged levels as instruments for the first differences of the endogenous variables. These are valid instruments if (i) the time-varying disturbance  $\epsilon_{i,t}$  is not serially correlated, and (ii) the explanatory variables  $X$  are weakly exogenous. In other words, if you consider the following dynamic panel data model:

$$y_{i,t} - y_{i,t-1} = \alpha y_{i,t-1} + \beta X_{i,t} + \epsilon_{i,t}, i = 1, 2, \dots, N, t = 3, 4, \dots, T \quad (43)$$

the basic assumptions of Arellano and Bond (1991) are

<sup>51</sup> Among others, Aghion et al. (2005) apply a panel estimation to test for business-cycle effects of volatility.

<sup>52</sup> As discussed in section 2, valid external instrumental variables for inflation are not available.

$$E[y_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0, \quad \text{for } s \geq 2; t = 3, \dots, T \quad (44)$$

$$E[X_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0, \quad \text{for } s \geq 2; t = 3, \dots, T \quad (45)$$

where  $y_{i,t}$  is the dependent variable,  $X_{1,i,t}$  a vector of endogenous and exogenous explanatory variables,  $N$  the number of cross-sections,  $T$  the number of time-periods,  $v_t$  the error term and  $\beta$  and  $\delta$  parameters to be estimated.

In addition, Blundell and Bond (1998) apply supplementary moment restrictions on the original model in levels, whereby lagged differences are used as additional instrument for the endogenous and predetermined variables in levels.<sup>53</sup> Given that  $E[y_{i,t}, \mu_i]$  is mean stationary, the Blundell and Bond (1998) estimator incorporates the additional moment restrictions:

$$E[(y_{i,t-1} - y_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0 \quad (46)$$

$$E[(X_{i,t-1} - X_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0 \quad (47)$$

Hence, they require 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. However, this estimator requires mean stationarity. In all estimations, we employ heteroscedasticity- and serial correlation robust standards errors.

We construct the series of aggregate TFP-growth, as a residual from the human capital augmented Solow-model.<sup>54</sup> 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 ( $\delta$ ) 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.<sup>55</sup> 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

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<sup>53</sup>Concerning the firm-level data, we impose one instrument for each variable and lag distance (collapse option), rather than one for each time period, variable, and lag distance in the case of the GMM system estimator. This restriction on the instrumental variable matrix reduces efficiency, but reduces computational requirements significantly. Moreover, we limit the number of lags to six in the case of the Arellano-Bond estimator.

<sup>54</sup>The inclusion of various control variables reduces the effective size of the panel to a minimum of 68 countries in some estimations.

<sup>55</sup>The investment series starts for 54 countries in 1950, for 17 in 1955 and for the remaining 17 in 1960.

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  $k$ .<sup>56</sup> 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.<sup>57</sup>

Inflation is measured by the first difference of the real consumer price index from the World Development Indicator database (WDI).<sup>58</sup> Moreover, we include the following institutional control variables: the government share relative to real GDP (both from the PWT), the amount of trade in goods as % of GDP, the terms of trade and an index of overall property rights (Fraser Institute of Economic Freedom database). To measure the degree of financial development we incorporate the amount of private credits issued by deposit money banks as % of GDP (*credit*) from Beck and Levine (2000). Apart from the index of property rights and the share of the government, we specify all other variables as potentially endogenous.<sup>59</sup>

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<sup>56</sup>We note that this explanatory power decreases significantly if  $\alpha$  exceeds 0.5, which, however, does not comply with existing empirical estimates.

<sup>57</sup>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.

<sup>58</sup>The base year is 1995. We also employ the producer and price index and report both if the results differ notably.

<sup>59</sup>We note that the qualitative results do not change if we consider the government share as an endogenous variable or additionally include the private share of investments. Moreover, private investments are insignificant so that they may influence GDP-growth, but not TFP-growth.

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