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**Abstract**

This paper employs a dynamic stochastic general equilibrium model with a financial market friction to rationalize the empirically observed negative relationship between inflation and total factor productivity (TFP). Specifically, an empirical analysis of US macroeconomic time series establishes that there is a negative causal effect of inflation on aggregate productivity. Rather than taking the productivity process as exogenous, the model is therefore set up to feature an endogenous component of TFP. This is achieved by allowing physical investment to be channelled into two distinct technologies: a safe, but return-dominated technology and a superior technology which is subject to idiosyncratic liquidity risk. An agency problem prevents complete insurance against liquidity risk, and the scope for insurance is endogenously determined via the relevant liquidity premium. Since the liquidity premium is positively related to the rate of inflation, the model demonstrates how nominal fluctuations have an influence not only on the overall amount, but also on the qualitative composition of aggregate investment and hence on TFP. The quantitative relevance of the underlying transmission mechanism which links nominal fluctuations to TFP via corporate liquidity holdings and the composition of aggregate investment is corroborated by means of the quantitative analysis of the calibrated model economy as well as a detailed analysis of industry-level and firm-level panel data. Notably, the empirical findings are consistent with both the properties of the agency problem postulated in the theoretical model and its implications for corporate liquidity holdings and physical investment portfolios.

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# 1 Introduction

The starting point for this paper is the empirical finding of a negative relation between inflation and total factor productivity (TFP), both at business cycle frequency and over longer horizons. Economic interpretations of this correlation can pursue two ways, depending on the direction of causality that is stressed. Indeed, in standard (complete markets) monetary business cycle models featuring an exogenous productivity process and a quantity relation between money, output and prices, it is the case that - ceteris paribus - a negative productivity shock is associated with a higher rate of inflation. Hence, the premise in this class of models is a causal negative effect of TFP on inflation. However, given that TFP is taken to be an exogenous residual, this is an unsatisfactory situation; the reason is that we are left with a "measure of our ignorance" (Abramovitz, 1956) in order to explain economic processes of first priority. This paper takes a different route. While we do not question the merits of the aforementioned class of models for the purpose of studying macroeconomic dynamics, we reverse the underlying notion of causality between inflation and TFP by proposing that the latter variable can be seen as a function of the former one. This implies that TFP is no longer an exogenous residual, but becomes an endogenous variable which is determined in the general equilibrium of the economy. Empirically, the findings emerging from US aggregate time series data at quarterly and yearly frequency provide robust evidence in favor of this hypothesis. In particular, higher inflation is significantly found to negatively affect TFP(-growth), whereby the exogeneity of inflation cannot be rejected; thus, there is evidence that the negative relation between inflation and TFP is indeed due to a causal effect from inflation to TFP.

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

In view of above arguments, it is evident that the present paper borrows from both business cycle and growth theory: It considers monetary and technological shocks as well as their interaction with a specific financial markets friction, but at the same time endogenizes the aggregate productivity process via an endogenous technology choice which is catalyzed by this friction.[1] Here, we focus on the corresponding cyclical and steady state implications, but abstract from the pertinent endogenous growth effects.[2] Instead, we elaborate on the source of market incompleteness which limits financial markets' capability to provide liquidity to the corporate sector. In particular, we detail a set of predictions regarding the interaction of variations in the liquidity premium with certain supply-side characteristics at the industry level; moreover, following Holmström and Tirole (1998), we provide an explicit framework which illustrates how these interaction effects can be *endogenously* derived from a particular entrepreneurial agency problem. Hence, constrained-efficient contracting in the face of incomplete insurance against idiosyncratic liquidity shocks delivers a number of implications concerning the reaction of the productive sector to monetary policy shocks and the way in which industry-level characteristics affect specific industries' sensitivity to such shocks. Specifically, following movements in the nominal interest rate, the response of industries which are more profitable and more exposed to advanced technologies is predicted to be more pronounced.

In order to assess the quantitative and empirical relevance of the proposed transmission mechanism, we adopt a twofold strategy: *One the one hand*, we interpret our model as a literal business cycle model and calibrate it to US data. The calibrated benchmark economy is then compared to alternative economies whose basic structure is identical, but where either monetary shocks are absent or the steady state rate of inflation is varied. Comparing the respective model-generated moments, we conclude (i) that, by generating an investment-composition driven variation in TFP, monetary policy shocks can account for a significant proportion of macroeconomic fluctuations, and (ii) that systematic changes in the level of inflation induce sizeable changes in the level of TFP. *On the other hand*, in order to substantiate the empirical relevance of our basic hypothesis that nominal fluctuations affect the composition of aggregate investment, we complement our empirical findings pertaining to aggregate US data by an analysis of disaggregate industry-level and firm-level panel data. In doing so, we provide evidence consistent with (i) the implications of constrained-efficient contracting with respect to the postulated agency problem, as well as (ii) the notion that corporate liquidity holdings are used as a precautionary buffer stock to hedge investment into advanced technologies and that the scope of such insurance is negatively affected by the level of inflation. We view these findings as strongly supportive of our theory.

[1]For a similar approach, compare the recent paper by Aghion et al. (2006) who paraphrase the situation as follows: *"The modern theory of business cycles gives a central position to productivity shocks and the role of financial markets in the propagation of these shocks; but it takes the entire productivity process as exogenous. The modern theory of growth, on the other hand, gives a central position to endogenous productivity growth and the role of financial markets in the growth process; but it focuses on trends, largely ignoring shocks and cycles."*

[2]An endogenous growth perspective is adopted in Evers, Niemann and Schiffbauer (2007).

The rest of the paper is organized as follows. The next section briefly synthesizes the established empirical findings on the effects of inflation on economic performance and reviews the related literature. Then, Section 3 provides detailed evidence on the relationship between inflation and TFP in the US economy. Against this background, Section 4 proposes a business cycle model as the theoretical framework for formulating our main hypotheses. Section 5 examines the quantitative properties of the calibrated benchmark economy as well as those of alternative model economies. In Section 6, we undertake an empirical analysis of (panel) data at different levels of aggregation in order to underpin our proposition that the composition of aggregate investment is crucially affected by the firm-level conditions for insurance against liquidity risk. A final section concludes, while some auxiliary information, including the explicit derivation of the solution to the financial contracting problem, is relegated to the Appendix.

# 2 Related literature

**Empirical literature:** In line with the present paper's focus, we organize our reading of the relevant empirical work in two steps: First, we draw on the literature to provide evidence on the relationship between inflation and economic performance, also shedding light on the respective effects on factor accumulation and aggregate productivity. Second, we resort to evidence from disaggregate firm-level data which provides valuable background information with respect to the transmission mechanism proposed in this paper.

Applying cross-sectional and panel growth regressions for yearly data, Fischer (1993) finds a negative correlation between inflation and economic growth.[3] The author 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. He starts from the presumption that adverse supply shocks are the main source of the potential 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 the relevant subsamples and is therefore led to the conclusion that inflation is exogenous with respect to growth. Second, by means of a growth accounting exercise, Fischer decomposes GDP-growth into its components and detects a robust negative relation between inflation on the one hand and the growth rate of capital, but also of TFP on the other hand. These two results have striking implications: They indicate that the negative correlation between inflation and GDP-growth cannot be (exclusively) due to adverse technology shocks. And they demonstrate that, even after controlling for factor accumulation and employment, the negative effect of inflation on growth persists; that is, there must be some inflation-driven mechanism which records in terms of decreased aggregate productivity.

The model we develop in Section 4 proposes that inflation, by making the provision of liquidity more costly, affects investment in a way that shifts activity from superior to return-

[3]Other contributions include De Gregorio (1992, 1993), Barro (1996), Bruno and Easterly (1998) and Easterly (2005). Generally, three potential mechanisms are put forward to rationalize the negative relationship: (i) the adverse effects on economic performance of distortions in the informational content of the price level due to aggregate uncertainty; (ii) the reduction in capital accumulation stemming from a temporary hold up of investment decisions in the presence of aggregate uncertainty; (iii) the inflation tax on returns from capital and R&D investment if investors must hold cash-in-advance.

dominated, but safer technologies. A natural way to operationalize arguments concerning the composition of aggregate investment is to use data on R&D expenditures to proxy investment in superior technologies. Wälde and Woitek (2004) report the overall *level* of R&D expenditure to be procyclical. Conversely, Aghion et al. (2006) focus on the cyclical variation of R&D as a *share* of total investment. On the basis of dynamic panel estimations, they find that the R&D share and aggregate investment have markedly different business cycle properties, which hints at the potential importance of a decomposition of aggregate investment in order to account for business cycle phenomena.

At the disaggregate level, our study seeks to empirically assess how nominal fluctuations impact on firms' investment decisions when financial markets are incomplete.[4] The basic take of our theory is that the availability of corporate liquidity is a crucial determinant for firm-level investment. To get some guidance on the potential power of this mechanism, we resort 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.[5] The authors establish that firms with better outside financing opportunities tend to hold a lower fraction of their total assets in the form liquid assets, and that firms with strong growth opportunities and riskier cash flows hold relatively high ratios of cash to total non-cash assets.[6] Therefore, 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. corporate liquidity is held as a hedge against production risk. As to the quantitative importance of corporate cash holdings, the authors report the mean over the firms in their sample of the ratio of cash to net assets at 18%, while the median amounts to 6%. 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. In the present paper we will elaborate on this hypothesis.

**Theoretical literature:** Characterizing a theoretical framework for an empirically plausible monetary transmission mechanism is the subject of a large set of macroeconomic models set up either in flexible or sticky price environments.[7] Our own model presents a flexible price economy generating monetary non-neutrality via a CIA constraint and the additional assumption of limited asset market participation;[8] an important empirical phenomenon replicated in models characterized by limited asset market participation is the *liquidity effect*, i.e. a fall in nominal interest rates following an (unexpected) monetary expansion. We augment a simple monetary model along these lines by a financial market friction which is motivated by an entrepreneurial

[4]For a review of the literature on corporate investment see Hubbard (1999).

[5]Most theoretical and empirical studies of corporate cash holdings start from 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.

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

[7]Compare e.g. Christiano, Eichenbaum and Evans (1997, 2005) and the references therein.

[8]See Cooley and Hansen (1989, 1998) for monetary business cycle studies based on CIA constraints and Lucas (1990), Fuerst (1992) or Christiano and Eichenbaum (1992, 1995) for developments of the limited participation framework.

moral hazard problem and gives rise to a well-defined corporate demand for liquidity. Starting from the contribution by Bernanke and Gertler (1989), there is an extensive literature dealing with the interaction of financial market frictions and the monetary transmission process. In this context, the dynamics of corporate investment and the heterogeneity of firms' responses to monetary policy shocks have received particular attention.[9] Here, we make no attempt to systematically review this literature; instead, we concentrate on contributions developing some of the aspects which feature prominently in our own model.

The key propagation mechanism we invoke to explain the negative relation between inflation and TFP is an investment composition effect in the presence of incomplete financial markets. In a real economy, Aghion et al. (2006) use a similar decomposition of aggregate investment in order to examine how credit constraints affect the cyclical behavior of productivity-enhancing investment. To that end, the authors develop a growth model where investment can be sunk into either a short-term project or a long-term project which enhances future productivity. Importantly then, aggregate productivity has both an exogenous and an endogenous component. The exogenous component is specified as in a conventional real business cycle model, whereas the endogenous component is driven by the mass of long-term projects that have been successfully completed in the past. Similar to our "advanced" technology, survival of long-term projects is uncertain because they are subject to idiosyncratic liquidity shocks which - for reasons left unspecified - can only be imperfectly insured. In this setup, the assumed stochastic structure of aggregate shocks alters the amount of scarce resources available to insure idiosyncratic liquidity risk in a procyclical fashion. As a consequence, the survival probability of any given productivity-enhancing project is procyclical which generates an investment composition effect giving rise to further procyclical momentum in the process for productivity growth and the business cycle. Another paper concerned with the composition of aggregate investment when financial markets are incomplete is Angeletos (2007). He 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. One particular model variant considers the general equilibrium properties of an economy where there is the choice of investing into either privately-held risky projects or public equity, wherby the latter allows to pool idiosyncratic risks. One of the model's implications then is that, quite similar to what will happen in the model economy developed in section 4, incomplete markets reduce TFP by shifting resources away from the more risky, but also more productive private equity investment.

Both Aghion et al. (2006) and Angeletos (2007) are concerned with real general equilibrium economies; hence, nominal aspects do not play any role. Moreover, in contrast to our own model, the implications for the economy's cyclical dynamics critically hinge on the assumption that uninsured idiosyncratic investment risk evolves in a countercyclical fashion. The present paper addresses both these issues at the same time. We set up a monetary business cycle model to show how the effects of financial market frictions on the composition of physical investment are shaped by the relative price for insuring superior investment activities, the *nominal interest rate*. This nominal rate is affected by monetary fluctuations and is determined in the model's general equilibrium such as to equilibriate the supply of short-term credit by the household sector with the demand for short-term credit from in the productive sector. Finally, in order to

[9] A selection of general contributions includes Bernanke and Gertler (1995), Bernanke, Gertler and Gilchrist (1996, 1999) and Carlstrom and Fuerst (1997); Cooley and Quadrini (2006), Fisher (1999) and Gertler and Gilchrist (1994) are concerned with heterogenous firm dynamics.

better understand the determinants of the interaction between the nominal interest rate and the scope for liquidity provision, we explicitly specify the source of market incompleteness which gives rise to uninsured idiosyncratic risk.[10] This allows us to derive a number of theoretical predictions which can be empirically examined.

# 3 Empirical evidence on the relationship between inflation and aggregate productivity

In this section, we use US time series data and adopt an instrumental variable approach to (i) document how inflation and aggregate productivity are related at business cycle frequency and to (ii) establish that the causal effect of inflation on TFP-growth is transmitted via corporate portfolio choices. That is, we complement the work of Fischer (1993) by employing alternative econometric methods and by examining the transmission channel in more detail. We exploit both quarterly and yearly data since it is not a priori clear whether the effect of nominal fluctuations on TFP fully materializes within a quarter.

As a starting point, we examine the interactions between TFP-growth and inflation at the aggregate level. We employ the first difference of TFP rather than its level since our methodology requires the inclusion of stationary variables.[11] The TFP series is constructed as the residual from the aggregate production function implied by the calibrated one-sector neoclassical growth model to be set out in Section 4.[12] Inflation is derived as the first difference of the consumer price index.[13] Moreover, we include GDP-growth and the private investment share relative to GDP as additional endogenous variables. The rationale behind this is that in standard monetary business cycle theories, the effect of inflation on real economic activity (GDP-growth) is due to the adverse impact on aggregate investment of the inflation tax or increased aggregate uncertainty associated with higher rates of inflation.[14]

Table 1 reports the results of an unrestricted VAR for quarterly and yearly frequencies as well as the corresponding Granger causality tests. The information criteria suggest the inclusion of a lag length of one in both cases;[15] hence, the Granger causality test reduces to a simple exclusion test of the first lag of the corresponding variable. The information contained in Table 1 reveals that inflation reduces TFP-growth in the subsequent period at a quarterly as well as a yearly frequency. This effect is significant on a 5% and 1% level, respectively, and

[10]Specifically, we embed the contracting problem discussed in Holmström and Tirole (1998) into our business cycle model. Kato (2006) adopts a similar approach, but in a real model. Meh and Quadrini (2006) consider a model with endogenous market incompleteness with respect to individual investment risk.

[11]Indeed, we cannot reject the null hypothesis of non-stationarity (p-value of 0.623) if we apply an augmented Dickey-Fuller test including a trend and two lags for US quarterly TFP data (167 observations).

[12]At yearly frequency, the correlation between the growth rates of our calibrated TFP-series and of the relevant series published by the Bureau of Labor Statistics (BLS) is 0.89; quarterly series are not available from the BLS. For further details, see Appendix C.

[13]The base year is 1995. We also employ the GDP deflator; however, we exclusively report the estimates based on consumer prices since the results are very similar in both cases.

[14]See Cooley and Hansen (1989), Chari, Jones and Manuelli (1995), Jones and Manuelli (1990), Ramey and Ramey (1995) or Stockman (1981) for a discussion of such theories.

[15]We stress that the negative (joint) effect of the lags of inflation on TFP-growth is robust to the inclusion of additional lags of the endogenous variables (1-4) at both frequencies. The additional tables are available from the authors upon request.

works independently from the adjustment of the private investment share and GDP-growth. In addition, we find that inflation Granger causes private investment at neither frequency. We infer that, in our sample, the transmission channel of inflation does not rest on private factor accumulation. This result underpins our hypothesis that inflation affects the composition rather than the overall level of private investment.[16] Finally, inspection of reverse causality from TFP-growth towards inflation shows that TFP-growth reduces inflation in the subsequent period at a yearly (significant at a 5% level), but not at quarterly frequency.

These results confirm a negative relation between inflation and TFP-growth at business cycle frequencies. The specific mechanism we put forward in this paper implies that an increase in inflation reduces corporate liquidity holdings which are used as insurance against the risk associated with physical investment relying on advanced technologies. The reduced liquidity holdings, in turn, induce a shift in the composition of investment and hence aggregate changes in TFP. A (non-structural) representation of this mechanism is given by the following system of equations:

$$\Delta \mathcal{T}_t = \alpha^{\mathcal{T}} + \beta^{\mathcal{T}} C_t + X_i' \gamma^{\mathcal{T}} + \epsilon_t^{\mathcal{T}} \quad (1a)$$

$$C_t = \alpha^{C} + \beta^{C} D_t + X_i' \gamma^{C} + \epsilon_t^{C} \quad (1b)$$

$$D_t = \alpha^{D} + \beta^{D} \pi_t + X_i' \gamma^{D} + \epsilon_t^{D}, \quad (1c)$$

where $\Delta \mathcal{T}$ is TFP-growth, $C$ is investment composition, $D$ are aggregate corporate liquidity holdings, $\pi$ is inflation and $X$ is a vector of covariates which affect all variables. In the following, we want to test the macroeconomic mechanism underlying system (1). Therefore, we exploit firm-level US data from the Compustat database and average across firms to obtain the relevant aggregate measures. Following Opler et al. (1999), we approximate investment composition by corporate investments in R&D and corporate liquidity holdings by the amount of cash and marketable securities, both relative to total assets. Moreover, we include average operating income, total assets and the amount of long term debt as additional control variables. To deal with an endogeneity problem of average R&D ratios and corporate liquidity holdings with respect to TFP-growth in the sense of $E(C_t \mid \epsilon_t^{\mathcal{T}}) \neq 0$, $E(D_t \mid \epsilon_t^{C}) \neq 0$, we apply an instrumental variable approach. Specifically, in view of potential contemporaneous feedback effects from TFP-growth to inflation, we assume $E(\pi_{t-1} \mid \epsilon_t^{\mathcal{T}}) = 0$ and employ lagged inflation as an instrument. In fact, the pattern of estimated coefficients from the unrestricted VAR suggests that the first lag of inflation is exogenous to TFP-growth since it Granger causes TFP-growth, while the lagged dependent variable of TFP-growth itself is not significant. If, in addition, the lag of inflation is correlated with average R&D ratios and corporate liquidity holdings (which we illustrate below), it is a valid instrument for these endogenous measures in equations (1a) and (1b). Furthermore, we consider the nominal interest rate ($\tilde{R}$) as an alternative measure of nominal fluctuations and apply its first lag as an additional instrument for the endogenous measures in these equations.[17] This allows us to test for the validity of our instruments by employing a Hansen test of overidentifying restrictions. Consequently, we use the first lags of inflation and the nominal interest rate as exogenous instrumental variables to

[16]Similarly, Ramey and Ramey (1995) and Aghion et al. (2006) call the effect of macroeconomic uncertainty on aggregate investment into question.

[17]The nominal interest rate is represented by the yield on corporate bonds (Moody's Seasoned Aaa Corporate Bond Yield) because the latter is the closest proxy for firms' cost of external finance.

estimate via the general method of moments (GMM) the causal effect of investment composition and average corporate liquidity holdings on TFP-growth. The Hansen test statistic indicates a well-specified econometric model in all reported estimations; furthermore, we always include a lagged dependent variable and incorporate heteroscedasticity-robust standard errors in all estimations. Summing up, we separately estimate the equations:

$$\Delta \mathcal{T}_t = \alpha_C^{\mathcal{T}} + \beta_C^{\mathcal{T}} C_t + X_i' \gamma_C^{\mathcal{T}} + \epsilon_{C,t}^{\mathcal{T}} \tag{2a}$$

$$\Delta \mathcal{T}_t = \alpha_D^{\mathcal{T}} + \beta_D^{\mathcal{T}} D_t + X_i' \gamma_D^{\mathcal{T}} + \epsilon_{D,t}^{\mathcal{T}}, \tag{2b}$$

whereby we treat $C$ and $D$ as endogenous and model them respectively as:

$$C_t = \alpha_C^C + \beta_1^C \pi_{t-1} + \beta_2^C \tilde{R}_{t-1} + X_i' \gamma_C^C + \epsilon_{C,t}^C \tag{3a}$$

$$D_t = \alpha_D^D + \beta_1^D \pi_{t-1} + \beta_2^D \tilde{R}_{t-1} + X_i' \gamma_D^D + \epsilon_{D,t}^D \tag{3b}$$

The results for US yearly data are reported in Table 2. Columns one to four are concerned with equations (2a) and (3a). The first column displays a positive correlation between the average R&D investment ratio and TFP-growth. The corresponding coefficient is significant on a 1% level. This positive correlation is independent of changes in average firm size, average operating income across firms, average value of corporate long-term debt and aggregate private and government investment shares. Moreover, the Arellano-Bond (1991) test for autocorrelation indicates the absence of first and second order serial correlation in the error terms. In the next two columns, we instrument advanced (R&D) investments by the first lags of inflation and the nominal interest rate, whereby column two does not employ the set of exogenous controls. In both cases, the results reveal a positive causal effect of advanced investment on TFP-growth which is significant on a 1% level. In addition, the Hansen test shows that the first lags of inflation and the nominal interest rate are valid instruments. Finally, we display the (modified) first stage regression in column four, whereby we excluded the nominal interest rate.[18] The first stage regression indicates a negative impact of the first lag of inflation on advanced investments. The corresponding coefficient is significant on a 1% level. In columns five to eight, we repeat the same exercise for equations (2b) and (3b), now instrumenting for our second endogenous transmission variable. First, we detect a positive significant contemporaneous correlation between the average corporate liquidity holdings and TFP-growth. The subsequent IV-estimations reveal that causation is indeed running from average corporate liquidity holdings to TFP-growth. The Hansen test indicates the validity of our instruments in both specifications. Finally, the (modified) first stage regression reports a strong negative impact of lagged inflation on average corporate liquidity holdings which is significant on a 1% level. Summing up, on the basis of annual US time series we find support for our model hypothesis which proposes that inflation and nominal interest rates reduce TFP-growth in the short-run by affecting average corporate liquidity holdings and the composition of firm-level physical investment portfolios.

Table 3 is concerned with the same questions, but for quarterly frequency. Due to the higher frequency, we now use the first two lags of inflation and the nominal interest rate as instrumental variables. We find a positive correlation between quarterly average R&D ratios and TFP-growth; as evidenced by columns two and three, applying an IV-approach reveals

[18]For unfiltered data, the correlation coefficient between CPI inflation and the nominal interest rate (Moody's Seasoned Aaa Corporate Bond Yield) is 0.42 (0.55) at yearly (quarterly) frequency.

that causation is running from advanced (R&D) investments to TFP-growth. The first lag of inflation features a negative correlation with the average R&D ratio, which is significant on a 1% level. The results for firms' average quarterly liquidity holdings are less clear-cut. We do not detect a significant positive correlation between this endogenous measure and TFP-growth at a quarterly frequency. Accordingly, at quarterly frequency the IV-approach does not confirm a significant impact of average corporate liquidity on TFP-growth even though the former is negatively influenced by lagged inflation. Overall, the results based on quarterly data appear less robust than the previous ones, which suggests that firms' adjustment in terms of their liquidity holdings or investment portfolios to changes in the level of inflation might not be swift enough to record at quarterly frequency.

To sum up, for US data we find a robust negative empirical relation between inflation and TFP-growth which is independent of changes in the private investment share or GDP-growth. A Granger causality test indicates that causality is running from inflation to TFP-growth. These two empirical observations challenge the presumption of conventional monetary business cycle theories which take the aggregate productivity process as exogenous or stipulate that real effects of inflation are transmitted via changes in the aggregate quantity of investments. The results of the IV-approach suggest that, on average, the aggregate negative effect of inflation on TFP is due to firm-level variations in liquidity holdings and investment composition.

# 4 The model

In view of above empirical findings, we now propose a one-sector model of a monetary economy as a tractable structure formalizing the economic intuition underlying our proposed transmission mechanism. As hinted in the Introduction, the model's key ingredients are (i) limited asset market participation, (ii) endogenous technology choice, and (iii) incomplete financial markets. The economy is populated by two sets of agents, households and entrepreneurs, each of unit mass. The production sector is characterized by two distinct intermediate input goods, labelled "basic" and "advanced" corresponding to the characteristics of the two constant-returns-to-scale technologies which are used to produce them,[19] and by a simple aggregation technology that combines the two intermediate goods to the final market good. Each entrepreneur runs an individual firm producing *both* intermediate input goods, though in distinct projects utilizing the respective technology. The final market good is produced by anonymous firms in a perfectly competitive market environment. In addition, there is a market for financial intermediation which is also assumed to be perfectly competitive. Finally, there is a government ("monetary authority") which implements macroeconomic policies. These policies, together with a set of exogenous shocks, expose the economy to aggregate uncertainty.

The timing structure underlying our model is as follows. Time is discrete, and within each period $t$, there are three points in time: one at the beginning of the period, denoted $t^-$, one at an interim stage when the vector $s_t$ of aggregate shocks materializes and information about them is revealed, and finally one at the end of the period, denoted $t^+$. The aggregate shocks in our model are productivity shocks $\mathcal{A}_t$, $\mathcal{V}_t$ to the two intermediate technologies as well as a shock $\mathcal{J}_t$ to government policy (to be specified later); hence, we have $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$. Apart from

[19]As a general rule, variables pertaining to the basic input good are indicated by the variable/superscript $k$, while $z$ is the relevant indicator for the advanced input good.

these aggregate shocks, there are purely idiosyncratic liquidity shocks $\xi_t^i$ to the single advanced technology project run by an individual entrepreneur. We now turn to a detailed description of the environment in which the economy's agents interact and define their decision problems. The exposition of the solution to the agents' problems as well as of the competitive equilibrium are relegated to the Appendix A; the most important equilibrium implications are discussed in in Section 4.6.

## 4.1 Households

Households enter a given period $t$ with claims to two distinct capital stocks $(k_t, z_t)$ accumulated from the past together with a nominal wealth position $M_t$. At time $t^-$, households divide their nominal wealth into resources $Q_t$ disposable for consumption later in the period and deposits $M_t - Q_t$ with a financial intermediary which earn a net interest rate $(\tilde{R}_t - 1)$.[20] After aggregate shocks have materialized, households rent out their technology-specific physical capital to the entrepreneurs who run the projects producing the basic and advanced input good, respectively. Similarly, they supply labor $h_t^{k,H}$ to basic and $h_t^{z,H}$ to advanced projects, resulting in an aggregate labor supply of $h_t^H = h_t^{k,H} + h_t^{z,H}$, whereby households are indifferent as to where their labor is employed.[21] As an equilibrium consequence, households will receive the same nominal wage $W_t^{k,H} = W_t^{z,H} = W_t^H$ in both projects. At time $t^+$, households receive the returns from labor and capital and make consumption and investment decisions. However, there is a cash constraint on the goods market with the consequence that a household's current expenditure for consumption $c_t^H$ and physical investment $x_t$ must be covered by the resources $Q_t$ earmarked for consumption plus a fraction $\theta$ of its current wage earnings. The household has preferences over sequences of consumption and labor supply; hence, the household problem is to maximize lifetime utility:

$$E_{0^-} \sum_{t=0}^{\infty} \beta^t u(c_t^H, h_t^H) \tag{4a}$$

subject to the cash constraint:

$$Q_t + \theta W_t^H h_t^H \geq P_t[c_t^H + x_t], \tag{4b}$$

an equation describing the evolution of nominal assets:

$$\begin{aligned} M_{t+1} &= Q_t + \theta W_t^H h_t^H - P_t[c_t^H + x_t] + \tilde{R}_t[M_t - Q_t + \mathcal{J}_t] \\ &+ R_t^k k_t + R_t^z z_t + (1-\theta) W_t^H h_t^H + \Upsilon_t, \end{aligned} \tag{4c}$$

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; moreover, there is a law of motion for aggregate capital $K_t = k_t + z_t$, which accounts for depreciation and technology-specific adjustment costs $\Phi(\cdot)$:

$$x_t = (k_{t+1} + z_{t+1}) - (1-\delta)(k_t + z_t) + \Phi(k_t, k_{t+1}) + \Phi(z_t, z_{t+1}) \tag{4d}$$

[20] This timing convention is standard in monetary models which feature a limited participation assumption on the household side; compare e.g. Lucas (1990).

[21] Where necessary, variables pertaining to the household sector will be denoted with a superscript $H$; similarly, the superscript $E$ is used to indicate variables pertaining to entrepreneurs.

## 4.2 Entrepreneurs

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

### 4.2.1 Intermediate input goods

Each of the two intermediate input goods is produced in an environment of perfect competition. Both input goods require capital as well as labor for production, but they 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 insuring an individual advanced project against this idiosyncratic liquidity risk is endogenously determined via a (constrained-efficient) financial contract. The need for this insurance arises as a consequence of an entrepreneurial moral hazard problem which prevents the efficient refinancing of projects and calls for the commitment of liquidity at the ex ante, rather than the ex post stage. A key distinction between the two technologies is the relevance of entrepreneurial moral hazard for the successful completion of production processes: In particular, we assume the basic technology to be free from the moral hazard problem such that the standard theory of corporate finance applies here; conversely, production by means of the advanced technology is subject to ex post entrepreneurial moral hazard. Another friction that is relevant for both tehnologies is an advance payment requirement, which necessitates borrowing working capital in order to pay wages; specifically, the parameter $\theta \in [0, 1]$ represents the fraction of the wage bill to be financed in advance.

**Basic technology:** Employment of labor and capital inputs $(l_t^k, k_t)$ for the basic technology is chosen such as to maximize time $t^+$ profits, whereby the vector of prices $(P_t^k, W_t^k, R_t^k, \tilde{R}_t)$ is taken as given. The basic technology producing intermediate goods is assumed to be homogenous of degree one and features labor augmenting technological progress at the exogenous rate $\gamma$. For simplicity, we employ the Cobb-Douglas form:

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

Similarly, a Cobb-Douglas aggregator converts household and entrepreneurial labor inputs into their effective composite, and agent-specific wages aggregate to a composite wage rate:

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

Hence, the problem when employing the basic technology is:

$$\begin{aligned}\max_{\{k_t, l_t^k\}} \Pi_t^k &= P_t^k\left(\mathcal{A}_t\varphi(k_t, l_t^k)\right) - W_t^k l_t^k - R_t^k k_{t-1} - \theta(\tilde{R}_t - 1)W_t^k l_t^k \\ &= P_t^k y_t^k - C(W_t^k, R_t^k, \tilde{R}_t; y_t^k). \end{aligned} \tag{5}$$

**Advanced technology:** Apart from controlling the basic production plan, each entrepreneur also runs a single advanced technology project. For any such project, the production plan is complicated by the risk that it is hit by a liquidity shock[22] which may trigger project termination before it yields any return. We assume that liquidity risk $\tilde{\xi}_t^i$ is proportional to planned revenue $P_t^z\tilde{y}_t^z$ and that the normalized liquidity shock $\xi_t^i \equiv \frac{\tilde{\xi}_t^i}{P_t^z\tilde{y}_t^z}$ is distributed according to a continuous distribution function $G(\xi_t^i)$ with associated (strictly positive) density $g(\xi_t^i)$. As for the basic intermediate goods, there is a Cobb-Douglas aggregation of the respective labor inputs by households and entrepreneurs, and the technology is given by a Cobb-Douglas production function under constant returns to scale which allows for exogenous labor augmenting technological progress:

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

An individual entrepreneur brings the amount $E_t^i$ as private equity into her intermediary firm. The advanced production plan and the hedge against liquidity shocks are then determined as part of a constrained-efficient contract between the entrepreneur and the financial intermediary.

## 4.3 Financial intermediation

The financial intermediary (or 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 loans market at a gross nominal interest rate $\tilde{R}_t$. At the loans market, this supply meets the demand for financial assets which comes from two sources: First, entrepreneurial firms demand short term credit in order to meet the advance financing requirement for a fraction $\theta$ of their respective wage bills. Second, entrepreneurs demand liquidity $D_t$ to be held as a buffer stock insuring their respective advanced technology projects. Hence, financial market clearing requires:

$$M_t - Q_t + \mathcal{J}_t = \theta W_t L_t + D_t, \tag{6}$$

where $W_t$ and $L_t$ are the aggregate wage rate and labor input across households and entrepreneurs and across the two intermediary technologies. Above condition simply stipulates

[22] The liquidity shock admits a variety of interpretations. It can be thought of as a simple cost overrun, as a shortfall of revenue at an interim stage which could have been used as an internal source of refinancing or as adverse information relating to the project's end-of-period profitability.

that the equilibrium interest rate $\tilde{R}_t$ balances the supply of loans with the corporate demand for funds due to its advance financing requirement and its need for precautionary liquidity. The financial intermediary operates after aggregate uncertainty is resolved. While lending to projects employing the basic technology proceeds in a frictionless market, lending to advanced technology projects is complicated by an entrepreneurial moral hazard problem which is dealt with by a financial contract. Two key implications of this contracting scheme are that firm bankruptcy is an equilibrium phenomenon and that the intermediary must commit funds to individual advanced technology projects before these projects' idiosyncratic liquidity needs are known. Therefore, it is important to recognize that the financial intermediary is able to pool idiosyncratic risks across individual projects because, as a consequence, it is sufficient for the financial intermediary to break even on an individual credit relationship in expectation.[23] 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. We next turn to a detailed description of the specific contracting problem in our model.

**Financial contracting:** Following Holmström and Tirole (1998), the sequencing of events underlying an individual advanced project's within-period[24] contracting problem can be decomposed into three stages. At *stage one*, after aggregate uncertainty with respect to $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$ is unveiled, the entrepreneur running an individual advanced project and holding an equity position $E_t$ in it contracts with the financial intermediary to pin down its production plan and refinancing provisions. In particular, the refinancing provisions determine the degree of insurance against idiosyncratic liquidity risk.[25] Given $s_t$, a contract between the financial intermediary (outside investor) and the entrepreneur 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 entrepreneur 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 project is hit by an idiosyncratic liquidity shock $\xi_t$. If the shock is met by appropriate refinancing, the project can continue; otherwise it is liquidated. We assume that the liquidity shock is verifiable, but it is shown in Holmström and Tirole (1998) that nothing changes if only the entrepreneur observes the shock as long as she

[23] Moreover, the intermediary's risk pooling capability also facilitates insurance of households' claims against individual advanced projects; the financial intermediary can therefore be thought of not only as matching supply of and demand for short-term credit, but also as a mutual fund pooling all household claims against advanced projects. The consequence is that, from an individual household's perspective, idiosyncratic risk $\xi_t^i$ is hedged, while aggregate risk from $s_t = \{\mathcal{A}_t, \mathcal{V}_t, \mathcal{J}_t\}$ remains relevant.

[24] Although the advanced production plan is conditional on the predetermined entrepreneurial equity position $E_t^i$, the factor demand problem itself is not dynamic because entrepreneurial asset accumulation proceeds mechanically and there is no intertemporal incentive provision. Moreover, since the financial contract turns out to be linear in $E_t^i$, the distribution of equity across entrepreneurs does not matter and exact aggregation is possible. From now on, we will therefore drop the superscript $i$.

[25] It is important to realize that the financial contract is negotiated after fresh cash $\mathcal{J}_t$ has been injected into the economy. Consequently, our concept of corporate liquidity is real in the sense that there is no nominal rigidity which, upon an increase in the price level, would discount the effective insurance capacity of any given nominal amount of liquid assets; what is affected by nominal fluctuations, though, is its relative price, the liquidity premium $(\tilde{R}_t - 1)$.

does not benefit from diverting resources. After the continuation decision, there is scope for moral hazard on the part of the entrepreneur in that she can exert effort to affect the distribution of production outcomes. Specifically, we make the extreme assumption that, conditional on continuation, exerting effort guarantees a gross return of $P_t^z \tilde{y}_t^z = P_t^z \mathcal{V}_t f(z_t, l_t^z)$ 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 project revenue conditional on survival; in particular, we have: $B_t = bP_t^z \mathcal{V}_t f(z_t, l_t^z) = bP_t^z \tilde{y}_t^z$ with $0 < b < 1$.[26] 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 all entrepreneurs operating the advanced technology; since liquidity risk is idiosyncratic, the intermediary is therefore able to pool the risk inherent in the investments across individual 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 corresponding to a continuation policy which prescribes project continuation if and only if the liquidity shock is such that $\xi_t \leq 1$. 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 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 $C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)$, respectively, then solves the following second best program of maximizing the entrepreneur's net return:

$$\max_{\mathcal{C}_t} \int \left\{ \Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) \right\} dG(\xi_t) - E_t \tag{7a}$$

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

$$\int \left\{ \tau_t(\xi_t) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) - \Gamma_t(\xi_t) \xi_t \tilde{R}_t P_t^z \tilde{y}_t^z \right\} dG(\xi_t) \geq C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) - E_t \tag{7b}$$

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

$$\Gamma_t(\xi_t) P_t^z \tilde{y}_t^z - \tau_t(\xi_t) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) \geq \Gamma_t(\xi_t) b P_t^z \tilde{y}_t^z \qquad \forall\, \xi_t, \tag{7c}$$

[26] Note, however, that the specific value of $b > 0$ will not matter as long as the constrained-efficient contract to be derived in Appendix A.3 delivers an interior solution.

where $\tilde{y}_t^z = \mathcal{V}_t\left(z_t\right)^{\alpha^z}\left((1+\gamma)^t l_t^z\right)^{1-\alpha^z}$ is the project's output conditional on survival and:

$$\begin{aligned} C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right) &= MC_t^z\left(W_t^z, R_t^z, \tilde{R}_t\right)\tilde{y}_t^z = \frac{1}{\mathcal{V}_t}\left(\frac{R_t}{\alpha^z}\right)^{\alpha^z}\left(\frac{[1+\theta(\tilde{R}_t-1)]W_t^z}{(1-\alpha^z)}\right)^{(1-\alpha^z)}\tilde{y}_t^z \\ &= [1+\theta(\tilde{R}_t-1)]W_t^z l_t^z + R_t^z z_t \end{aligned} \quad (8)$$

are the associated total costs which accrue when a output level of $\tilde{y}_t^z$ is targeted in case of survival; by constant returns to scale, the marginal cost $MC_t^z(\cdot)$ of increasing planned output $\tilde{y}_t^z$ is constant. Note how the specification of this problem, by means of the participation constraint (7b), incorporates the requirement that the investor who bears the risk of project failure be willing to finance the project, whereby the outside investor commits both the factor remuneration and the interim resources needed to meet the liquidity shock. Appendix A.3 shows that the solution to program (7) in terms of the optimal cutoff $\hat{\xi}_t^*$ is determined via the following first order condition:

$$\int_0^{\hat{\xi}_t^*} G(\xi_t)d\xi_t = \frac{MC_t^z(\cdot)}{P_t^z}\frac{1}{\tilde{R}_t} \quad (9)$$

This condition illustrates that the cost of providing liquidity at the interim stage, which has to be obtained in the financial market at the financial rate $\tilde{R}_t$, as well as the gap between prices and marginal costs $\frac{P_t^z}{MC_t^z(\cdot)}$ play a key role in shaping the optimal contract.

**Implementation and aggregate liquidity demand:** The key element of the solution to program (7) is the second best cutoff value $\hat{\xi}_t^*$ up to which refinancing needs will be covered such that production can proceed. In order to hedge against such liquidity shocks, 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 $\hat{\xi}_t^0 = \frac{(1-b)}{\tilde{R}_t} < \hat{\xi}_t^*$. 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 risky production activities can be insured by means of corporate liquidity holdings, there arises the related question of whether there is a second best policy that features firms (rather than the intermediary) holding liquidity. These questions are dealt with in Appendix A.4. Here, suffice it to stress (i) that second best contracting can indeed be implemented via liquidity holdings at the firm level and (ii) that under financial intermediation, which efficiently economizes on the use of scarce liquidity by pooling liquidity risk across projects, the aggregate demand for liquidity is:

$$D_t = \left[\int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t)d\xi_t\right] P_t^z \tilde{y}_t^z \quad (10)$$

## 4.4 Market good

The market good is simply aggregated over the two technology-specific intermediate input goods supplied by the entrepreneurs:

$$y_t = \left( \zeta^{\frac{1}{\rho}} {y_t^k}^{\frac{\rho-1}{\rho}} + (1-\zeta)^{\frac{1}{\rho}} {y_t^z}^{\frac{\rho-1}{\rho}} \right)^{\frac{\rho}{\rho-1}}, \tag{11}$$

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

$$y_t^k = \zeta \left( \frac{P_t^k}{P_t} \right)^{-\rho} y_t \qquad \text{and} \qquad y_t^z = (1-\zeta) \left( \frac{P_t^z}{P_t} \right)^{-\rho} y_t \tag{12}$$

We assume perfect competition on the final goods market; therefore, the aggregate price level is determined by the marginal input cost, i.e. the intermediate good prices, which are constant from the final good firm's perspective. Consequently, zero profits imply:

$$P_t = \left( \zeta {P_t^k}^{1-\rho} + (1-\zeta) {P_t^z}^{1-\rho} \right)^{\frac{1}{1-\rho}} \tag{13}$$

For future reference, we also define the respective aggregates of the two factors of production, capital $K_t = k_t + z_t$ and labor $L_t = l_t^k + l_t^z$, as well as the elasticities of aggregate output with respect to the intermediate input levels:

$$\omega_{yk,t}^y \equiv \frac{dy_t/y_t}{dy_t^k/y_t^k} = \zeta^{\frac{1}{\rho}} \left( \frac{y_t^k}{y_t} \right)^{\frac{\rho-1}{\rho}} \qquad \text{and} \qquad \omega_{yz,t}^y \equiv \frac{dy_t/y_t}{dy_t^z/y_t^z} = (1-\zeta)^{\frac{1}{\rho}} \left( \frac{y_t^z}{y_t} \right)^{\frac{\rho-1}{\rho}} \tag{14}$$

## 4.5 Government policy

In order to close the model, a specification for government policy is needed. The focus of our analysis is not a normative one; therefore, to keep things simple, we will consider an exogenous process for monetary policy which consists of periodic injections $\mathcal{J}_t$ of money in the financial market. $\mathcal{J}_t$ is implicitly defined as $\mathcal{J}_t = (e^{mg_t} - 1)(M_t + A_t)$, where $mg_t$ is the gross rate of money growth. Hence, the aggregate of nominal wealth held by households and entrepreneurs is updated according to:

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

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

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

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.

## 4.6 Equilibrium implications

The solution to the agents' optimization problems, the details on the implementation of financial contracting subject to entrepreneurial moral hazard as well as the definition of a competitive equilibrium are all contained in Appendix A. In the following, we put on record a set of important equilibrium implications which are informative with respect to the effects of monetary fluctuations on corporate liquidity demand and the composition of firms' physical investment. They are derived on the basis of the financial contracting scheme outlined in Section 4.3, which pins down the optimal amount of liquidity provision $\hat{\xi}_t^*$, and will be the object of our empirical analysis below.

- $\mathcal{H}1$: *Ceteris paribus*,[27] an increase in $\tilde{R}_t$ leads to a lower cutoff $\hat{\xi}_t^*$:

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

Thus, quite intuitively, higher nominal interest rates $\tilde{R}_t$ imply less hedging against idiosyncratic liquidity shocks because the financial intermediary's participation constraint gets tighter in line with the increased costs of providing liquidity. In order to examine the effects of other changes in the economic environment on firms' liquidity demand, we establish two auxiliary results. *First*, increased volatility of the liquidity shock distribution $G(\cdot)$ in the sense of a mean-preserving spread implies a lower cutoff value $\hat{\xi}_t^*$; formally $\frac{d\hat{\xi}_t^*}{d\sigma_\xi} < 0$.[28] The intuition behind this result is that increased risk makes the option to terminate any given advanced project more valuable. The empirical prediction therefore is that firms operating in a more volatile environment are insured less comprehensively. *Second*, situations where production by means of the advanced technology is more profitable, i.e. situations characterized by higher markups of prices over marginal costs $\frac{P_t^z}{MC_t^z(\cdot)}$ are predicted to feature a lower $\hat{\xi}_t^*$; formally $\frac{d\hat{\xi}_t^*}{d(P_t^z/MC_t^z)} < 0$.[29] The reason for the poorer insurance of more profitable projects is the contracting trade-off between ex ante and ex post rationing underlying the efficient choice of $\hat{\xi}_t^*$: While a more generous provision with liquidity has the advantage of withstanding larger shocks, the higher associated costs necessarily imply 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 to fluctuations in the nominal interest rate.

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

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

[27] The claimed result obtains if, to a first approximation, $\frac{P_t^z}{MC_t^z(\cdot)}$ remains constant. The result then follows from total differentiation of condition (9). 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.

[28] 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.

[29] This follows from total differentiation of condition (9), for given $\tilde{R}_t$.

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

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

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

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

Moreover, starting from the supposition that the economy's productive activity is organized based on a set of distinct technologies available to a continuum of entrepreneurial firms, we can infer a measure $\mathcal{T}_t$ of aggregate productivity. The argument put forward within the framework of our model is that $\mathcal{T}_t$ is not simply determined as an exogenous residual process, but also affected by endogenous shifts in the composition of economic activity. In detail, as shown in Appendix B, we derive our aggregate measure of TFP such that changes in $\mathcal{T}_t$ can be decomposed as follows:

$$\widehat{\mathcal{T}_t} \;=\; \omega_{yk,t}^y\widehat{\mathcal{A}_t} + \omega_{yz,t}^y\left(\widehat{\mathcal{V}}_t + \omega_{\hat{\xi}^*,t}^G\widehat{\hat{\xi}_t^*}\right), \tag{18}$$

where $\widehat{x} \equiv \frac{dx}{x}$ and where $\omega_{\hat{\xi}^*}^G = \frac{g(\hat{\xi}^*)\hat{\xi}^*}{G(\hat{\xi}^*)}$ denotes the elasticity of the survival probability with respect to the cutoff value for liquidity shocks $\hat{\xi}^*$. Expression (18) illustrates how changes in $\mathcal{T}_t$ can be expressed as a weighted sum of changes in the technology-specific productivity levels $\mathcal{A}_t$ and $\mathcal{V}_t$. The endogenous weights attached to $\widehat{\mathcal{A}_t}$ and $\widehat{\mathcal{V}}_t$ are given by the elasticity terms $\omega_{yk,t}^y$ and $\omega_{yz,t}^y$ defined in (14), which underpins the importance of the sectoral composition of production activities; moreover, since the elasticity terms are formulated in terms of *realized* intermediate output levels, the effect of $\widehat{\mathcal{V}}_t$ is amended by the term $\omega_{\hat{\xi}^*,t}^G\widehat{\hat{\xi}_t^*}$ which reflects how the level of *realized* advanced sector output $y_t^z$ (as opposed to $\tilde{y}_t^z$, the relevant quantity *conditional on survival*) responds to changes in the degree of insurance against liquidity risk provided to advanced projects. Thus, besides the exogenous processes $\mathcal{A}_t$ and $\mathcal{V}_t$, there are two endogenous sources of fluctuations in measured TFP: First, shifts in the allocation of physical investments $(k_t, z_t)$ - an investment composition effect; and second, for a given composition of aggregate investment, changes in the effectiveness of converting hired factor inputs $(z_t, l_t^z)$ into *realized* output $y_t^z$ - an insurance effect in response to changes in the liquidity premium. Now, building on equations (15) and (18), the model's key implication with respect to aggregate fluctuations is obtained.

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

$$\frac{d\mathcal{T}_t}{d\tilde{R}_t} = \omega_{yz,t}^y\omega_{\hat{\xi}^*}^G\frac{d\hat{\xi}_t^*}{d\tilde{R}_t} < 0, \tag{19}$$

where the inequality follows from $\omega_{yz,t}^y, \omega_{\hat{\xi}^*}^G > 0$ and (15).

Finally, differentiation of equation (19) facilitates a prediction concerning the differential impact of nominal fluctuations across economies characterized by different production structures:

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

$$\frac{d}{d\omega^{y}_{yz,t}}\left(\frac{d\mathcal{T}_t}{d\tilde{R}_t}\right) = \omega^{G}_{\hat{\xi}^*}\frac{d\hat{\xi}^*_t}{d\tilde{R}_t} < 0, \tag{20}$$

  which follows from $\omega^{G}_{\hat{\xi}^*} > 0$ and (15).

# 5 Quantitative model analysis

The model is calibrated to US time series at quarterly frequency, whereby we employ macroeconomic aggregates and amend them by industry-level data in order to calibrate the parameters that pin down the relative employment of "basic" versus "advanced" technologies. A description of the data as well as the details of our calibration exercise such as the specification of functional forms are contained in Appendix C. The calibrated benchmark set of parameters is summarized in Table 4. In order to assess the quantitative role of nominal shocks for aggregate fluctuations and in particular for the endogenous evolution of TFP, we now analyze the statistical properties of the model economy, employing the routines proposed by Sims (2001). As far as the monetary transmission mechanism is concerned, the effects of an unanticipated monetary expansion are twofold: First, there is a liquidity effect, recording as a drop in nominal interest rates on impact, and second, there is an inflationary effect which may take time to materialize. The induced dynamic pattern of nominal interest rates is key in shaping firms' investment with respect to its overall amount, but also with respect to its composition. Importantly, the compositional effects are associated with changes in aggregate productivity. Against this background, the main purpose of the following analysis is to examine within the framework of our model economy whether monetary shocks can indeed account for a sizeable fraction of fluctuations in TFP.[30] We approach this question based on a series of numerical experiments. *First*, we simulate the model for our benchmark calibration and confront the generated moments with empirical US business cycle statistics. *Second*, we consider the same model economy, but shut down money shocks as a source of nominal fluctuations; this exercise allows us to decompose the volatility of key macroeconomic aggregates - particularly of TFP - into the fractions that are attributable to money and technology shocks, respectively. *Finally*, we are interested in the steady state effects of increased nominal distortions, an issue that we approach by comparing the equilibrium allocations of alternative economies which are indexed by different rates of inflation along their balanced growth paths.

**Empirical and simulated business cycle statistics:** Table 5 documents empirical and simulated business cycle statistics. Of particular interest are standard deviations as well as contemporaneous correlations of several macroeconomic aggregates with real GDP. We point out that, empirically, aggregate productivity is procyclical with respect to real GDP, whereas both the level and the growth rate of TFP are negatively correlated with the rate of inflation (in

[30] In contrast, it is not our principal objective to replicate salient features of the US monetary business cycle.

terms of both the GDP deflator and CPI inflation) and different nominal interest rate measures, the own rate on $M2$ and the yield on corporate bonds.[31] Our benchmark model economy is characterized by a steady state quarterly rate of inflation of 1.31% and a remaining parametrization as summarized in Table 4. The linearized model is simulated, and the columns labelled "benchmark economy" in Table 5 report standard deviations as well as cross-correlations with aggregate output; for TFP, we also present cross-correlations with nominal interest rates and inflation. A comparison with the empirical statistics reveals that the model-generated standard deviations are consistent with the empirical pattern as far as relative magnitudes are concerned, but that the implied volatility of output falls short of its empirical counterpart, while the model statistics for hours worked and aggregate productivity reflect the increased (as compared to the data) volatility of the monetary variables. Turning to the contemporaneous correlations, we find that hours and aggregate investment display less procyclicality with aggregate output than observed in the data and that, counterfactually, a negative comovement of inflation and real GDP is predicted. On the other hand, the benchmark model generates interest rate correlations (0.07) which strike a balance with respect to the diverging sign pattern of the two analyzed nominal interest rate measures' correlations (0.24 and $-0.17$). Notably, also the comovement of TFP with real GDP is accurately replicated at 0.55 (versus 0.58 in the data). Turning to the correlations with nominal interest rates, the key statistic for our purpose is the negative contemporaneous correlation of TFP which the benchmark model predicts at $-0.53$ versus, depending on the interest rate measure, $-0.29$ or $-0.44$ in the data. The empirical correlation of TFP with the two different inflation measures is $-0.35$ or $-0.22$, whereas the benchmark model predicts that inflation and aggregate productivity do hardly comove over the cycle.[32] While not reported, we also note that inflation plays the role of a leading indicator for nominal interest rates; similarly, past money growth is found to be associated with higher nominal interest rates, whereas the contemporaneous correlation is negative due to the liquidity effect of monetary expansions. Taken together, these facts suggest a systematic effect of monetary policy on TFP, which is transmitted via fluctuations in the nominal interest rate and - according to our model - the associated changes in the composition of aggregate investment.

**Variance decomposition and key correlations:** To further assess the relevance of this mechanism, we resimulate the model, employing the same parametrization, but shutting down monetary shocks by setting $\sigma_j = 0$. This exercise facilitates a variance decomposition and is also informative with respect to the cyclical effects of monetary policy. The relevant statistics are also reported in Table 5 under the heading "$\sigma_j = 0$". Importantly, our quantitative analysis implies that $17.16\% = (1.34 - 1.11)/1.34$ of the fluctuations in aggregate productivity can be attributed to monetary policy shocks (see column four). Obviously, the quantitative importance of these shifts in aggregate productivity due to changes in the composition of aggregate investement critically depends on the relative importance of corporate liquidity demand in

[31] The contemporaneous correlations for the growth rate of TFP, which are not reported in Table 5, are $\rho(\Delta\mathcal{T}, \pi\,(\text{dGDPdef})) = -0.23$, $\rho(\Delta\mathcal{T}, \pi\,(\text{dCPI})) = -0.22$, $\rho(\Delta\mathcal{T}, \tilde{R}\,(\text{M2})) = -0.15$ and $\rho(\Delta\mathcal{T}, \tilde{R}^{corp}) = -0.06$.

[32] The explanation for this somewhat puzzling finding is related to the liquidity effect: Not only does an expansionary monetary innovation lead to inflation, but it also induces a decrease in nominal interest rates, thereby increasing aggregate productivity. Our rudimentary benchmark model features an excessively strong liquidity effect; therefore, the strongly positive comovement between inflation and measured TFP upon impact nets out the otherwise negative correlation between the two variables.

overall short-term credit, $\frac{d}{d+\theta wL}$; the latter ratio, in turn, is affected by the advance financing parameter $\theta$. Specifically, pushing $\theta$ from its calibrated benchmark value of 0.25 towards zero implies that the relative importance of the demand for corporate liquidity to insure advanced technology investments increases. As a consequence, the sensitivity of aggregate productivity to fluctuations in the liquidity premium (the bulk of which can be attributed to monetary disturbances) is magnified. This is illustrated in column six which, for the alternative economy with $\theta = 0.05$, reports the fraction of TFP fluctuations to be traced to monetary shocks at 34.88%. In contrast, the standard deviation of aggregate investment is hardly affected across the alternative model economies. The same parameter variations have also important implications for the correlation pattern between macroeconomic aggregates as illustrated by the columns at the right end of Table 5. In particular, we point out that the contemporaneous correlation between TFP and nominal interest rates undergoes a sign switch from $-0.53$ to 0.15 when shutting down monetary shocks, while a decrease in $\theta$ is seen to intensify the negative comovement between the two variables. Similar conclusions can also be drawn with respect to the comovement of inflation and TFP.

**Steady states:** At a more fundamental level, distortions via increased rates of inflation and nominal interest rates affect the economy's real allocation also along a balanced growth path. Some important indicators for the induced distortions are summarized in Table 6, which compares steady state allocations across economies indexed by different rates of inflation. Moving from left to right, it can be seen that increased rates of inflation one-to-one feed into higher nominal interest rates and thus into a higher liquidity premium for insuring advanced sector production. The reason for this is that the liquidity premium faced by firms is effectively determined by the households who, due to their CIA constraint, require a higher compensation for carrying money from one period to the next one. Higher nominal rates then change the allocation in that (i) the composition of aggregate investment as measured by the ratio $\frac{z}{k}$ is shifted towards the basic technology, and (ii) the amount of corporate liquidity used to hedge advanced sector production decreases. The latter holds true both for the absolute real amount $d = \frac{D}{P}$ of corporate liquidity and two relevant measures of liquidity in relation to aggregate output, $\frac{d}{y}$, or the overall demand for short-term credit, $\frac{d}{d+\theta wL}$. The implication is that the survival probability $G(\cdot)$ of advanced projects successively decreases, which further aggravates the effect of the distorted composition of aggregate investment; this is evidenced by the ratio of realized sectoral outputs $\frac{y^z}{y^k}$ which declines by more than the relative allocation of physical capital. In line with the prediction of $\mathcal{H}4$, the relocation of resources induces a fall in aggregate productivity $\mathcal{T}$; as hinted above, this drop in TFP is the consequence of two things: (i) the shift in the composition of aggregate investment towards the basic technology, and (ii) the decreased insurance against liquidity risk in the advanced sector. Indeed, moving from an economy which is governed by a Friedman rule (first column) to an economy characterized by a money growth rate of 10% (column five) leads to a drop in TFP of 2.1%; similarly, moving from a non-inflationary steady state (column two) to the latter economy goes along with a drop in TFP of 1.7%. Finally, we mention that also some cyclical aspects of the alternative economies (indexed by their respective steady state rates of inflation) change as is evidenced by the correlation pattern of nominal interest rates presented in the last line of Table 6. Specifically, the adverse effects of interest rate shocks on TFP become more pronounced the higher the level of steady state inflation.

The results established on the basis of above experiments underpin that our proposed model may be a useful tool to understand how (inflation-driven) fluctuations in the nominal interest rate impinge on the cyclical behavior of macroeconomic aggregates and in particular on TFP. As far as the main phenomenon of interest, the negative causal effect of inflation and nominal interest rates on aggregate productivity, is concerned, the quantitative model analysis has demonstrated that not only cyclical fluctuations, but also level effects do play a quantitatively important role. Thus, at this stage, the model is consistent with the empirical evidence on the relationship and the inherent causality between macroeconomic aggregates documented in Section 3. The model has proposed a particular monetary transmission mechanism based on the qualitative composition of private investment portfolios and the importance of corporate liquidity holdings to hedge superior investment projects. Since this channel is identified neither via aggregate data nor the analysis of model-generated moments, we now investigate whether our specific predictions regarding firm behavior find empirical support in disaggregate data.

# 6 Empirical analysis of disaggregate data

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

## 6.1 Sectoral level

**Data and methodology:** Our model provides us with a set of firm-level predictions ($\mathcal{H}1$ - $\mathcal{H}3$) as well as aggregate implications ($\mathcal{H}4$ - $\mathcal{H}5$). It is straightforward to extend our one-sector model to a multi-sector setup, whereby each individual industrial sector is a replica of the representative production structure described in Section 4. The economywide TFP measures discussed in the context of $\mathcal{H}4$ and $\mathcal{H}5$ can then readibly interpreted as industry-specific productivity measures, and the contracting implications $\mathcal{H}1$ - $\mathcal{H}3$ do apply not only for individual firms, but also for industrial sectors. Hence, we can empirically test our hypotheses by means of industry-level data. In particular, as an implication of $\mathcal{H}2$, we are led to hypothesize that the response in terms of the cutoff $\hat{\xi}^*$ to movements in the nominal interest rate is stronger for firms operating in more volatile industries. A positive correlation between the rate of inflation and nominal interest rates[33] and the fact - compare equation (18) - that a lower $\hat{\xi}^*$ ceteris paribus leads to lower TFP-growth then together imply that the negative relation between TFP-growth and inflation is expected to be stronger in more volatile industrial sectors. In addition, we presume that firms operating in more productive sectors in terms of their historically realized TFP-growth have had access and are more exposed to superior investment opportunities and therefore depend more heavily on corporate asset holdings to insure against liquidity risk. Indeed, for given $\tilde{R}$, equation (8) delivers a link between the technology component $\mathcal{V}$ available to a firm on the one hand and its marginal cost $MC^z$ and therefore its profitability

[33]As already mentioned above, for unfiltered data, the correlation coefficient between CPI inflation and the nominal interest rate (Moody's Seasoned Aaa Corporate Bond Yield) is 0.42 (0.55) at yearly (quarterly) frequency.

$\frac{P^z}{MC^z}$ in case of survival on the other hand; the intuitive implication is that high productivity growth goes along with high potential profitability. Hence, from $\mathcal{H}3$, profitable firms operating in industries with high realized productivity growth are expected to react more sensitively to nominal fluctuations, and, from $\mathcal{H}5$, such fluctuations should affect sectoral TFP-growth more severely in industries with a better historical productivity performance.

We apply 3-digit industry-level data for the US to investigate these hypotheses. The productivity of US industrial sectors is measured by the yearly growth rate of real value added per industry from the UNIDO (2002) industrial statistics database. The yearly data are available for 28 industries from 1963-2000.[34] The classification of 3-digit US industries with respect to average volatility (standard deviation) and average growth of productivity in our sample are reported in Table 7. The correlation coefficient between these two rankings is positive 0.23 (s.e.=0.03) and significantly different from zero at a 1% level according to Spearman's rank correlation test. Hence, independence of both rankings is rejected, confirming that more volatile sectors tend to be characterized by higher average productivity growth.[35] Therefore, identifying industries that are highly exposed to the advanced technology (in the sense of a high $\omega^y_{yz}$) with volatile and strongly growing sectors, we operationalize our empirical analysis by means of $\mathcal{H}5$: We divide the sample according to the median, the first and the fourth quartile of both measures. According to our theoretical model, the differential impact of inflation on TFP-growth across the relevant subsamples should result from the different sensitivity of corporate liquidity holdings in response to nominal fluctuations and is expected to be more pronounced in the 14 (7) industries whose volatility/average productivity growth is above the median (in the first quartile). We control for industry-specific fixed effects in all estimations. Since the first lag of the growth rate (or level) of value added is not significant at conventional levels in any specification, we employ a static panel estimation. That is, we estimate the following model:

$$y_{i,t} = \alpha + \beta_1\pi_{t-1} + \beta_2(\pi_{t-1} * DV_i) + \beta_3 X_t + \eta_i + \epsilon_{i,t}, \qquad i = 1, 2, ..., N, t = 1, 2, ..., T, \quad (21)$$

where $y_{i,t}$ is the growth rate of real value added per industry, $\pi_{t-1}$ the first lag of inflation, $DV_i$ a dummy which amounts to one for industries with an above median (first quartile) volatility/mean, $X_t$ a vector of aggregate control variables, $N = 28$ the number of cross-sections, $T = 38$ the number of time-periods, $\eta_i$ industry-specific fixed effects, $\epsilon_{i,t}$ the error term and $\alpha$ and $\beta$ parameters to be estimated.[36] We cluster the error terms at the industry level so that the standard errors are robust to within-group (serial) correlation.[37] Inflation is measured as the change in the economywide consumer price index; we include the first lag of inflation due to the potential endogeneity of contemporaneous measures. Furthermore, we include the contemporaneous level and the first lag of the growth rate of GDP ($GDP-growth$), the private investment share ($inv-share$) and the amount of overall credit ($credit$) as control variables. The latter

[34]We have to confine ourselves with yearly data since, to our knowledge, quarterly data on value added at industry level are not available. Moreover, note that we deflate the value added series in each sector with the economywide GDP-deflator.

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

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

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

variable is often used as a proxy for the degree of financial market development in the literature.

**Results:** The first column in Table 8 reports the correlation between the first lag of inflation and the growth rate of real value added for the full sample. We find that a 1% increase in the economywide rate of inflation triggers, on average, a drop in the sectoral growth rate of real value added by 0.96% after controlling for changes in (lagged) GDP-growth, the private investment share and the overall supply of credit. The next two columns contrast the sensitivity of value added growth with respect to inflation in high and low volatility sectors (above/below median). Consistent with $\mathcal{H}2$, we detect that the negative impact of inflation is significant in both subsamples, but on average 61% higher in the 14 highly volatile sectors. In order to test for a statistical significance of the difference between both coefficients, we interact the lag of inflation with a dummy variable which amounts to one for high volatility industries (according to the median) and zero otherwise. Column four reveals that the interaction is negative and significant on a 10% level. That is, the distorting impact of an 1% increase in inflation aggravates, on average, by 0.32% if we focus on high volatility as opposed to low volatility sectors. This effect is even more pronounced if we compare the sensitivity in the seven most volatile sectors with the one in the residual 21 sectors (column five). In particular, the sensitivity of value added growth per industry with respect to inflation is, on average, 76% higher in the seven most volatile sectors. The difference is significant on a 5% level. Thus, as predicted by $\mathcal{H}2$, we are able to link the inflation-sensitivity of sectoral TFP-growth to the average sectoral volatility of productivity growth per industry. Columns six to seven of Table 8 classify the impact of inflation on productivity growth according to the median and first quartile of the observed average productivity growth of a given industry in the sample. In accordance with $\mathcal{H}3$ and $\mathcal{H}5$, column six reports that the negative impact of inflation is more pronounced in industries whose average productivity growth is above the sample median. Yet, the difference is not significant at conventional levels. Moreover, the coefficient is neither significant nor even positive if we focus on the seven sectors that experienced the highest average productivity increase in the sample.

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

## 6.2 Firm level

**Data and methodology:** Firm-level data allow for the most direct test of the specific transmission mechanism proposed by our model. Specifically, our theory predicts that firms react to nominal distortions which increase the liquidity premium by reducing their liquidity holdings used to hedge advanced investment projects ($\mathcal{H}1$) and by shifting their investment portfolios towards more secure, but also less productive projects. Thus, we expect that increased corporate liquidity holdings augment the investment in superior projects, while increased nominal interest rates, notably as a consequence of higher (expected) rates of inflation, reduce corporate liquidity holdings and trigger an adverse investment composition effect.

In order to test these hypotheses, we match the relevant variables employed in Section 3 with US firm-level data at quarterly as well as yearly frequency from the Compustat database. The latter data relate to the balance sheets of US non-financial firms and cover the effective time periods 1989:1-2000:4 and 1970-2000, respectively. In detail, we include the following firm-level data: R&D expenses, the amount of corporate liquidity measured as the sum of cash and marketable securities (*corp. liquidity*) and the amount of total assets (*assets*).[38] Here, R&D is used as a proxy for investment in superior technologies.[39] The *assets* variable, in turn, reflects overall corporate assets and thus controls for firm size. As hinted above, we use the US CPI-based rate of inflation and the yield on corporate bonds to investigate the effect of these macroeconomic variables on firm-level liquidity and investment portfolios.[40] In addition, where available, we exploit information on individual firms' S&P credit rating (*spdrc*)[41] as an additional control variable to isolate the effect of firm-specific credit conditions relative to the aggregate measure for the lending rate faced by non-financial firms.

In this context, we again point out the empirical evidence provided by Opler et al. (1999) based on yearly US firm-level data for 1970-1993. The authors proxy a firm's investment opportunities by its market-to-book value and/or its expenses for R&D, respectively; the risk associated with a firm's cash flow is measured by the standard deviation of its cash flows. The study finds that the value of liquid assets (cash and marketable securities) relative to total net assets averages at 18% for US non-financial firms. Furthermore, it establishes that firms with higher growth opportunities and riskier cash flows hold on average more liquid assets.[42] We see these empirical findings as strongly supportive of the relevance of corporate liquidity holdings for the purpose of insuring superior, but risky production activities. Against this background, we extend the analysis in Opler et al. (1999) by investigating the impact of inflation and nominal interest rates on corporate liquidity holdings and firm-level R&D expenses.

We have a balanced panel of over 150000 (97000) observations at quarterly (yearly) frequency.[43] We employ the Arellano and Bond (1991) GMM difference ($GMM-dif$) as well as the Blundell and Bond (1998) GMM system estimator ($GMM-sys$) because of the significance of the lagged dependent variable (e.g. lagged R&D levels).[44] These estimation procedures are

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

[39] If we interpret investment in superior technologies as investment in new technologies, while investment in less productive projects reflects production with established technologies, R&D expenses are the most appropriate candidate for an approximation of advanced investments projects.

[40] We stress that our standard errors are robust to serial correlation and hence are not subject to the caveat raised by Moulton (1990).

[41] The variable is an index number, ranging from 1 to 30 in our sample, whereby a higher value corresponds to a poorer credit rating.

[42] Notice that these latter findings relate to a sample comprising firms irrespective of the industrial sector they belong to. In contrast, our own empirical prediction ($\mathcal{H}2$) was empirically tested by means of industrial subaggregates. Hence, there is no inconsistency between the results in Opler et al. (1999) and our own findings reported in Section 6.1.

[43] Unfortunately, the S&P credit rating index is only available for roughly 12000 time observations.

[44] Similarly, Aghion et al. (2006) apply a (country-) panel estimation based on yearly data to test for business cycle effects of volatility.

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 $X_{i,t}$ are weakly exogenous.[45] In all estimations, we employ heteroscedasticity- and serial correlation robust standards errors. Finally, note that the mix of macroeconomic and microeconomic data allows for an inspection of causality. More specifically, the coefficient of inflation reflects the causal impact on an individual firm's (marginal) R&D expenses since the latter have no feedback effect on the aggregate level of inflation.

**Results:** In all estimations, we reject the presence of second-order autocorrelation. Furthermore, the Hansen test of overidentifying restrictions never rejects the validity of the instruments. Hence, all estimation specifications appear to be well-specified.[46] Table 9 summarizes our main results for the dynamic panel estimations at quarterly frequency.[47] In the first two columns, we use the amount of corporate liquidity as the dependent variable. The first column reports a negative coefficient of inflation, which is not significant at conventional levels, however. The second column displays a negative impact of the nominal interest rate on corporate liquidity holdings, which is significant on a 5% level. This coefficient suggests that, averaging across firms, a 1% increase in the nominal interest rate reduces liquidity holdings per firm by almost 1.4 million US$ in the same quarter. In particular, our estimation results are consistent with proposition $\mathcal{H}1$ derived in the context of the agency problem underlying our theoretical model. In both cases, we control for firm size (total assets), which - not surprisingly - has a positive effect on liquidity holdings.

The remaining columns of Table 9 have R&D expenses per firm as the dependent variable.

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

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

the basic assumptions of Arellano and Bond (1991) are $E[y_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0$, $E[X_{i,t-s}(\epsilon_{i,t} - \epsilon_{i,t-1})] = 0$ for $s \geq 2; t = 3, ...T$, where $y_{i,t}$ is the dependent variable, $X_{i,t}$ a vector of endogenous and exogenous explanatory variables, $N$ the number of cross-sections, $T$ the number of time-periods, $\epsilon_{i,t}$ the error term and $\alpha$ and $\beta$ parameters to be estimated. In addition, Blundell and Bond (1998) apply supplementary moment restrictions on the original model in levels, whereby lagged differences are used as additional instruments for the endogenous and predetermined variables in levels. [For practical purposes, we impose one instrument for each variable and lag distance (collapse option), rather than one for each time period, variable, and lag distance in the case of the GMM system estimator. This restriction on the IV-matrix reduces efficiency, but increases the number of overidentifying restrictions which are used to test for the validity of the instruments (Hansen test). Moreover, we limit the number of lags to six in the case of the Arellano-Bond estimator.] Given that $E[y_{i,t}, \mu_i]$ is mean stationary, the Blundell and Bond (1998) estimator incorporates the additional moment restrictions $E[(y_{i,t-1} - y_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0$, $E[(X_{i,t-1} - X_{i,t-2})(\eta_i + \epsilon_{i,t})] = 0$, which requires the additional assumption of no correlation between the differences of these variables and the country-specific effect. The authors show that this procedure is more efficient if explanatory variables are persistent; however, the estimator requires mean stationarity.

[46] As explained above, inflation and the nominal interest rate are considered as exogenous variables. The microeconomic variables are considered as (potentially) endogenous.

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

The third column illustrates that inflation has a negative causal impact on firm-level investments in R&D; the coefficient is significant on a 5% level. Keeping the amount of total assets fixed, a 1% increase in inflation reduces R&D expenses per firm on average by 0.9 million US$. Moreover, as evidenced by the positive coefficient on total assets, larger firms invest more in R&D. In view of the comprehensive empirical evidence[48] that larger firms have better outside financing opportunities, this suggests that R&D investments are constrained by a firm's financing opportunities. Importantly, the fourth column demonstrates that the distorting effect of inflation declines if we control for the amount of corporate liquidity holdings. We find that the coefficient of inflation is cut by one half and not significant any more at conventional levels. At the same time, an increase in liquid assets per firm enhances investments in superior technologies; the corresponding coefficient is significant on a 1% level.[49]

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

In Table 10, we report the firm-level evidence for data recorded at yearly frequency. The outline of the results follows the same logic as for Table 9. The first two columns reveal that an increase in either inflation or nominal interest rates substantially reduces corporate liquidity holdings. The two relevant coefficients are both significant on a 5% level. Moreover, inflation reduces R&D investment per firm. At a yearly frequency, the corresponding coefficient suggests that a 1% increase in inflation reduces a firm's R&D expenses on average by 0.47 million US$.[50] The distortionary effect of inflation declines by 20% if we additionally control for liquidity holdings per firm.[51] The direct effect of corporate liquidity holdings on R&D is close to the one at quarterly frequency and significant at a 1% level. In contrast to the quarterly findings, the coefficient of the nominal interest rate in the R&D regression, though still negative, is not

[48]Compare e.g. Hubbard (1998) and the references therein.

[49]Note that all qualitative results are also robust to the inclusion of industry rather than firm fixed effects; results are available from the authors upon request.

[50]We employ the Arellano-Bond estimator since the coefficient of the lagged dependent variable is close to one, indicating problems with the stationarity of R&D at yearly frequency which would contaminate the Blundell-Bond estimator.

[51]Yet, the decline in the inflation-coefficient is not statistically significant.

significant at conventional levels; there is even a sign switch if liquid assets are controlled for. In the last two columns of Table 10, we systematically exploit the information of the S&P credit rating. Specifically, we split the sample into two subsets: (i) firms with a "sound" credit ranking (below 12) and (ii) firms with a "poor" one (above 12). Following the logic of our model, one would expect that the negative impact of inflation on R&D is more pronounced for firms with worse access to external finance since the precautionary holding of marketable assets for the purpose of hedging liquidity risk becomes more important. Indeed, columns seven and eight display that the distortionary impact of inflation is six times higher for firms with a poor credit rating. Furthermore, a deterioration in the credit rating has a negative direct effect on R&D investments for the subset of firms with a relatively bad credit rating, while the effect is not significant for the subset of better-rated firms.

Summing up, the firm-level results show that inflation has a negative impact on firm-level investment in superior technologies. However, this effect disappears if corporate holdings of cash and marketable securities and individual firms' outside financing opportunities are controlled for. Thus, the impact of inflation on compositional investment decisions at the firm-level is actually due to variations in a firm's liquidity holdings and outside financing opportunities. Together with the results from the previous industry-level analysis, the empirical firm-level findings provide strong evidence in favor of the microeconomic mechanism underlying our theoretical propositions regarding the aggregate relation between inflation and investment composition-driven TFP-growth at business cycle frequency.

# 7 Concluding remarks

The main contribution of this paper is to document a negative causal effect of inflation on TFP at business cycle frequency and to propose a model to structurally rationalize this effect. On the basis of US quarterly and yearly time series data, we provide detailed empirical evidence supporting the hypothesis that nominal distortions have a negative effect on TFP-growth. We then propose a monetary business cycle model allowing for endogenous technology choice between a safe, but return-dominated technology and a superior technology which yields higher expected returns, but is subject to idiosyncratic liquidity shocks. Insurance against such liquidity risk is possible by holding a buffer stock of liquid assets, but an agency problem prevents complete insurance, whereby the scope for insurance is endogenously determined via the relative price for liquidity. In this environment, we demonstrate how nominal fluctuations affect not only the overall amount, but also the composition of aggregate investment and the degree to which advanced investments are hedged against liquidity risk. The direct consequence is an effect on aggregate productivity. Next, we show that the proposed monetary transmission mechanism as well as the model's equilibrium implications for corporate liquidity holdings and the composition of physical investment are consistent with US industry-level and firm-level panel data. Using industry-level data, we find that sectoral TFP-growth responds more sensitively to nominal fluctuations (i) in more volatile sectors and (ii) in sectors that are characterized by a relatively high historical TFP-growth. From firm-level data, we infer that investments in superior technologies, proxied by firm-level R&D expenses, (i) decline if the level of inflation or nominal interest rates increases and (ii) are positively related to corporate liquidity holdings. We regard these empirical findings as strongly supportive of our proposed transmission mechanism.

On the basis of numerical exercises we infer that monetary policy shocks can account for a significant proportion of the variations in TFP. In fact, the benchmark calibration of our model implies that some 17% of the variability in aggregate productivity can be attributed to monetary shocks. Consequently, our findings suggest that the role of monetary policy shocks for macroeconomic fluctuations has been underestimated. While the present paper's focus is on the business cycle implications of the investment-composition driven effects of monetary shocks, both the empirical analysis of US aggregate data and the analysis of our model indicate that also higher steady state rates of inflation have adverse implications on the evolution of TFP. In a companion paper, Evers, Niemann and Schiffbauer (2007), we therefore elaborate on the endogenous growth implications of our proposed transmission mechanism and, using country-level panel data, identify a robust negative causal effect of inflation on long-run TFP-growth. Our explanation is that inflation acts as a tax on the provision of liquidity to the corporate sector and thereby affects not only the capital accumulation decision, but also the technology choice decision which shapes the evolution of aggregate productivity.[52]

On more general grounds, the striking empirical evidence of a negative causal influence of monetary variables (inflation and nominal interest rates, respectively) on both short-run fluctuations and long-run growth rates of TFP fundamentally questions the orthodox modelling strategy of treating money supply shocks and shocks to aggregate technology, identified as a residual category labelled TFP, as orthogonal.[53] Against this background, there is a need for more theoretical and empirical work in order to better understand the implications of compositional variations in the utilization of production factors and their dependence on nominal macroeconomic conditions. In the present paper, we have stressed one relevant margin; complementary issues relating to government policies other than monetary policy as well as to the market environment in which (heterogenous) firms dynamically interact deserve particular attention.

[52] Compare Erosa (2001) for a similar argument.

[53] Implicitly, this insight already underlies the work by Fischer (1993).

# Appendix

# A Competitive equilibrium and financial contracting

Below, we present the optimality conditions characterizing the solution to the model economy's agents' decision problems, lay out the details of the financial contracting scheme between entrepreneurs and the financial intermediary and then define a competitive equilibrium.

## A.1 Optimal decisions: Households

The solution to the household problem (4) can be summarized by a set of optimality conditions which determine the household's equilibrium behavior. First, there is the Euler equation describing the optimal intertemporal allocation of nominal wealth:

$$E_{t^-}\left\{\frac{u_c(c_t^H, h_t^H)}{P_t} - \beta\tilde{R}_t\frac{u_c(c_{t+1}^H, h_{t+1}^H)}{P_{t+1}}\right\} = 0 \tag{22}$$

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

$$u_c(c_t^H, h_t^H)\left[1 + \Phi_2(i_t, i_{t+1})\right] = \beta E_t\left\{u_c(c_{t+1}^H, h_{t+1}^H)\left[(1-\delta) - \Phi_1(i_{t+1}, i_{t+2})\right] + \beta\frac{u_c(c_{t+2}^H, h_{t+2}^H)}{P_{t+2}}R_{t+1}^i\right\} \tag{23}$$

An immediate implication of the two equations (23) is that the technology-specific returns to capital must be equal in expectation, i.e. $E_t\{R_{t+1}^k\} = E_t\{R_{t+1}^z\} = E_t\{R_{t+1}\}$. Similarly, there are two optimality conditions which govern the household's consumption-leisure choice, thus pinning down the optimal supply of labor to either production plan $i = k, z$:

$$u_h(c_t^H, h_t^H) + \left[\theta\frac{u_c(c_t^H, h_t^H)}{P_t} + (1-\theta)\beta E_t\left\{\frac{u_c(c_{t+1}^H, h_{t+1}^H)}{P_{t+1}}\right\}\right]W_t^{i,H} = 0 \tag{24}$$

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

## A.2 Optimal decisions: Entrepreneurs

**Basic technology:** The entrepreneur's problem (5) when employing the basic technology reduces to a standard classical production plan: By constant returns to scale, efficient factor employment implies that marginal costs are independent of the quantity produced, i.e. $C(W_t^k, R_t^k, \tilde{R}_t; y_t^k) = MC_t^k(W_t^k, R_t^k, \tilde{R}_t; 1)y_t^k$. Then, from the assumption of perfectly competitive intermediate goods markets, it follows that the price of the basic intermediate good equals marginal costs, i.e. $P_t^k = MC_t^k(W_t^k, R_t^k, \tilde{R}_t)$. From the Cobb-Douglas specification of $\varphi(k_t, l_t^k)$, optimal factor demands for the basic production plan are:

$$k_t = \frac{\alpha^k P_t^k y_t^k}{R_t^k} \qquad \text{and} \qquad l_t^k = \frac{(1-\alpha^k)P_t^k y_t^k}{[1+\theta(\tilde{R}_t - 1)]W_t^k} \tag{25}$$

Finally, the price for the basic intermediate good is:

$$P_t^k = \frac{1}{\mathcal{A}_t}\left(\frac{R_t^k}{\alpha^k}\right)^{\alpha^k}\left(\frac{[1+\theta(\tilde{R}_t-1)]W_t^k}{(1-\alpha^k)}\right)^{(1-\alpha^k)} \tag{26}$$

**Advanced technology:** Production by means of the advanced technology is subject to an entrepreneurial ex post moral hazard problem. This agency problem is dealt with via a financial contract whose specification closely follows Homström and Tirole (1998) and is described next.

## A.3 Financial contracting

**Optimal factor input ratio and the cost function:** Part of an optimal contract must be to use factor inputs in a cost minimizing combination. Since factor demands are determined via the constrained-efficient contract $\mathcal{C}_t$ solving program (7), they will not only reflect the entrepreneur's profit maximization objective, but also the intermediary's need to break even in expectation. From the Cobb-Douglas specification, the possibility of project failure then requires that factors earn constant shares not of project revenue, but of the total costs $C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)$ associated with a targeted production scale $\tilde{y}_t^z$. Hence, the demands for capital and labor to be employed in a generic advanced project are:

$$z_t = \frac{\alpha^z C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)}{R_t^z} \qquad \text{and} \qquad l_t^z = \frac{(1-\alpha^z) C\left(W_t^z, R_t^z, \tilde{R}_t; \tilde{y}_t^z\right)}{[1+\theta(\tilde{R}_t-1)]W_t^z} \tag{27}$$

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

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

where $MC_t^z(\cdot)$ are the per unit costs of producing a targeted output level $\tilde{y}_t^z$; since the technology displays constant returns to scale, these per unit costs coincide with marginal costs. 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:** Consider 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.[54] Substituting from the binding participation constraint (7b) into the entrepreneur's net return (7a) yields:

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

[54]By well-specified, we mean (i) that there is no self-financing, and (ii) that the solution to the constrained-optimal contract features a finite investment level.

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 $\Gamma_t(\xi_t)$ then allows to rewrite the entrepreneur's net return as:

$$\Pi_t^F(\hat{\xi}_t) \;=\; \lambda_t(\hat{\xi}_t) MC_t^z(\cdot)\tilde{y}_t^z, \tag{28a}$$

where:

$$\lambda_t(\hat{\xi}_t) \;\equiv\; \left[\int_0^{\hat{\xi}_t} \frac{P_t^z}{MC_t^z(\cdot)}\left(1-\xi_t\tilde{R}_t\right) dG(\xi_t) - 1\right] \tag{28b}$$

In definition (28b), $\lambda_t(\hat{\xi}_t)$ denotes the *net social marginal return* on one unit invested in the individual advanced 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 (28a), 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 $b > 0$. Notice that general equilibrium considerations imply that the marginal net social return under both the first and the second best solution must be positive.[55] 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 (7b), 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 that is still consistent with incentive compatibility. Hence, the entrepreneur's incentive compatibility constraint (7c) is binding at the maximum pledgeable unit return:

$$\tau_t(\xi_t) = \frac{\Gamma_t(\xi_t)(1-b)P_t^z\tilde{y}_t^z}{MC_t^z(\cdot)\tilde{y}_t^z} \tag{29}$$

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 (29) into the investor's participation constraint (7b) to obtain:

$$\left[1 - \int \Gamma(\xi_t)\left((1-b) - \xi_t\tilde{R}_t\right)\frac{P_t^z}{MC_t^z(\cdot)} dG(\xi_t)\right] MC_t^z(\cdot)\tilde{y}_t^z = E_t \tag{30}$$

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 (30) implies that, given some $E_t > 0$, the expected (subject to

[55] 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.

idiosyncratic liquidity shocks) marginal return on outside investment is strictly smaller than one.[56]

Solving (30) for the maximum investment volume conditional on a given cutoff value $\hat{\xi}_t$, allows to write the project's investment capacity as:

$$MC^z_t(\cdot)\tilde{y}^z_t \;=\; \mu_t(\hat{\xi}_t)E_t, \tag{31a}$$

where:

$$\mu_t(\hat{\xi}_t) \;\equiv\; \frac{1}{1-\int_0^{\hat{\xi}_t}\left((1-b)-\xi_t\tilde{R}_t\right)\frac{P^z_t}{MC^z_t(\cdot)}dG(\xi_t)} \tag{31b}$$

is an *equity multiplier*, whose denominator specifies the amount of internal funds that the entrepreneur 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 (30). Finally, using (28a) and (31a), the entrepreneur's expected net payoff becomes:

$$\Pi^F_t(\hat{\xi}_t) = \lambda_t(\hat{\xi}_t)\mu_t(\hat{\xi}_t)E_t \tag{32}$$

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 (32). It is clear that $\hat{\xi}^*_t \in [\hat{\xi}^0_t, \hat{\xi}^{FB}_t]$: If $\xi_t < \hat{\xi}^0_t$, both parties prefer to continue ex post because both parties can realize gains on the sunk stage one investment; if $\xi_t > \hat{\xi}^{FB}_t$, both parties prefer to abandon the project because the net social marginal return of continuing is negative. Within the interval $[\hat{\xi}^0_t, \hat{\xi}^{FB}_t]$, 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 $MC^z_t(\cdot)\tilde{y}^z_t$ by increasing the equity multiplier $\mu_t(\hat{\xi}_t)$. After substitution from the definitions (28b) and (31b) into (32), it is straightforward to show that the optimal continuation value $\hat{\xi}^*_t$ can be found as the solution to the following problem:

$$\min_{\hat{\xi}_t} \frac{\tilde{R}_t\int_0^{\hat{\xi}_t}\xi_t dG(\xi_t) + \frac{MC^z_t(\cdot)}{P^z_t}}{G(\hat{\xi}_t)}, \tag{33}$$

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:

$$\int_0^{\hat{\xi}^*_t} G(\xi_t)d\xi_t = \frac{MC^z_t(\cdot)}{P^z_t}\frac{1}{\tilde{R}_t} \tag{34}$$

[56] Indeed, if this was not the case, investment would be self-financing and there would be no demand for liquidity at all in that the investor's participation constraint would be non-binding. A sufficient condition for ruling out self-financing is: $\int_0^{\hat{\xi}^0_t}\left((1-b)-\xi_t\tilde{R}_t\right)\frac{P^z_t}{MC^z_t(\cdot)}dG(\xi_t) < 1$. Observe that rewriting this condition yields $\lambda_t(\hat{\xi}^0_t) < b\frac{P^z_t}{MC^z_t(\cdot)}G(\hat{\xi}^0_t)$; then, it is apparent that $\hat{\xi}^{FB}_t = \hat{\xi}^0_t$ if $b = 0$, which leads to the conclusion that, in order to rule out self-financing, a positive wedge $\hat{\xi}^{FB}_t - \hat{\xi}^0_t > 0$ and therefore $b > 0$ are essential.

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

$$\Pi_t^F(\hat{\xi}_t^*) = \frac{\frac{1}{\tilde{R}_t} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \frac{(1-b)}{\tilde{R}_t}} E_t = \frac{\hat{\xi}_t^{FB} - \hat{\xi}_t^*}{\hat{\xi}_t^* - \hat{\xi}_t^0} E_t \tag{35}$$

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 reference, we define the *expected net return per unit of entrepreneurial equity* $E_t$ as:

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

Since the optimal contract is linear in the individual entrepreneur's equity position, any individual entrepreneur's conditions are also relevant in the aggregate. As a result, the first order condition (34) pins down the price level for the intermediate goods produced by means of the advanced technology:

$$P_t^z = \frac{1}{\tilde{R}_t \int_0^{\hat{\xi}_t^*} G(\xi_t) d\xi_t} \frac{1}{\mathcal{V}_t} \left( \frac{R_t^z}{\alpha^z} \right)^{\alpha^z} \left( \frac{[1 + \theta(\tilde{R}_t - 1)] W_t^z}{(1 - \alpha^z)} \right)^{(1-\alpha^z)} \tag{36}$$

## A.4 Implementation and discussion of second best policy

Aggregating across advanced projects, we can derive two measures of aggregate liquidity demand. The first one is relevant if liquidity provision is organized in a way that disregards the scope for risk sharing across entrepreneurs:

$$\bar{D}_t = \hat{\xi}_t^* P_t^z \tilde{y}_t^z \tag{37a}$$

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

$$D_t^* = \left[ \int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t \right] P_t^z \tilde{y}_t^z < \bar{D}_t \tag{37b}$$

It is clear that this latter concept requires some form of financial intermediation. Hence, drawing on Holmström and Tirole (1998), we turn to the institutional details supporting the implementation of the second best policy.

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 credit line implements the second best solution as long as it is provided free of charge, 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. Since the liquidity shocks are independent across projects, the aggregate amount of resources needed to cover refinancing needs at the interim stage is then given by $D_t^*$. At the level of an individual entrepreneur, 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 projects, 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 for each project, thus forgoing the potential to pool liquidity across them.[57]

Given our empirical interest, the question arises whether there is a second best policy which features the productive sector (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 entrepreneur will then use the obtained external finance to complement her own equity position $E_t$ sunk in the project by the maximum admissible amount $MC_t^z(\cdot)\tilde{y}_t^z - E_t$ and deposit her remaining liquid assets with the intermediary (at zero interest). Now, at stage two, when hit by a liquidity shock $\xi_t$, the entrepreneur must first use up her own asset position of $\check{\xi}_t P_t^z \tilde{y}_t^z$; only then can she 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 projects who receive shocks $\xi_t < \check{\xi}_t$. Obviously, this policy replicates the second best in terms of both the initial investment scale and the cutoff $\hat{\xi}_t^*$. Thus, it only remains to check whether above arrangement is feasible, which is the case since, from the definition of $\check{\xi}_t$, the supply of and demand for liquidity are equal at the aggregate level: $P_t^z \tilde{y}_t^z \check{\xi}_t = D_t^* = P_t^z \tilde{y}_t^z \int_0^{\hat{\xi}_t^*} \xi_t g(\xi_t) d\xi_t$. Further variations on the institutional structure implementing the second best, involving advanced sector projects 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 retun, are possible.

## A.5 Competitive equilibrium

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

1. *given prices, the allocation solves the household problem (4) as well as the basic and*

[57] In the benchmark section of their paper which features an exogenous supply of liquidity, Holmström and Tirole (1998) establish equivalence of the two discussed 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 sells at a premium $\tilde{R}_t - 1 > 0$), and agents have an incentive to economize on its usage. The consequence is that intermediated credit lines and decentralized corporate liquidity holdings are no longer equivalent.

*advanced production problems (5) and (7);*

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.*

# B TFP accounting

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

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

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

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

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

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

where the first equality is an implication of the definition (in terms of subaggregates for the respective intermediate goods) of TFP as the Solow residual. Similarly, for the advanced technology, we get:

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

From these equations, we can deduce overall TFP-growth as the weighted sum of productivity growth of the different technologies. Specifically, from (11), aggregate output is given by a CES aggregation of the intermediate outputs produced with the different technologies. Aggregate output growth can then be expressed as the composite of technology-specific growth rates:

$$\widehat{y} = \zeta^{\frac{1}{\rho}}\left(\frac{y^k}{y}\right)^{\frac{\rho-1}{\rho}}\widehat{y^k} + (1-\zeta)^{\frac{1}{\rho}}\left(\frac{y^z}{y}\right)^{\frac{\rho-1}{\rho}}\widehat{y^z} = \omega^y_{yk}\widehat{y^k} + \omega^y_{yz}\widehat{y^z}$$

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

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

# C Calibration and data sources

To operationalize the calibration exercise, functional forms need to be specified. As to household preferences, we postulate a Cobb-Douglas utility function in consumption $c^H$ and leisure $(1-h^H)$:

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

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

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

which guarantees that, as the economy grows, the average resources spent in terms of adjustment costs remain constant and that along a balanced growth path these costs are zero. Finally, the exogenous productivity shocks to intermediate goods production are assumed to obey the following autoregressive process:

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

where $\chi$ is a measure of the productivity gap between the advanced sector and the basic sector along the balanced growth path.

The parameters we set beforehand are the coefficient of relative risk aversion $\sigma = 2$ as well as $\Omega$ and $\eta$ which determine the relative importance of the entrepreneurs in the economy with respect to their labor supply and their accumulated wealth; in view of the parametrizations employed in the literature, we set $\Omega = 0.95$ and $\eta = 0.97$.[58] As to the parameters determined from the data, we first resort to relevant time series for the US at quarterly frequency (1959:1-2006:2) which were obtained from the Bureau of Economic Analysis (2006) and the Bureau of Labor Statistics (2006). Specifically, we set $\gamma = 0.0037$ to match the average growth rate of

[58] Compare e.g. Bernanke, Gertler and Gilchrist (1999) and the references therein.

real output per hour worked over our sample of 0.37% per quarter and $\beta = 0.98$ to match the average implied real interest rate - the difference between the nominal interest rate and the rate of inflation - of 2.7% over this sample. The preference parameter $\mu = 0.167$ is calibrated to be on average consistent with the consumption-leisure FOC (24), while $\alpha^k = \alpha^z = \alpha = 0.31$ are set to match the labor share of income.[59] Finally, $\delta = 0.0112$ is pinned down such as to match the average consumption of fixed capital. The investment adjustment cost parameter $\phi = 12.5$ is determined such as to match the empirical volatility of aggregate investment of 5.60%.

The critical parameter for our analysis is the fraction $\theta$ of the firms' wage bill that needs to be paid in advance because it pins down the quantitative importance of liquidity relative to overall short-term credit. We calibrate $\theta$ using the information on firms' balance sheets reported in Opler et al. (1999). There, the sample mean (median) of liquid assets over total assets net of liquid assets is at 18% (6%), while total (= short-term plus long-term) leverage is at 28% (25%). These numbers imply a ratio of liquid assets to total debt of 0.54 (0.23). The corresponding model statistic is $\frac{D}{D+\theta WL}$; we choose $\theta = 0.25$ such that the steady state value for this expression is at 0.36, falling in between the empirical reference statistics.

The composition of economic activity is mainly determined by the parameters $\rho$, $\zeta$ and $\chi$, which we calibrate from industry data, as well as by the agency cost parameter $b$ and the moments $\mu_\xi$, $\sigma_\xi$ of the liquidity shock distribution $G(\cdot)$, which is assumed to be lognormal. The parameters $b = 0.15$, $\mu_\xi = -0.75$, $\sigma_\xi = 0.75$ are jointly calibrated such as to generate a steady state with (i) an advanced project survival rate of 83% (corresponding to a failure rate of 4.6% across both technologies). In order to pin down the parameters $\rho$ and $\zeta$, we recover estimates for these parameters using annual industry-level data from the UNIDO (2002) industry database covering the period 1963-2000. These data provide disaggregate information on value added and output prices at industry level according to the Standard Industrial Classicication (SIC) system; we drop the government and the financial sector as well as industries with missing data and are left with 36 industries (see Table 7). We organize these remaining industries into two subaggregates, whereby the sorting criterion is the standard deviation of each industry's growth rate of value added over time. We interpret these subaggregates as the two intermediate production technologies in our model economy and use the associated relative prices to infer the parameters of interest from (12). In particular, from total differentiation of these relative demand schedules, one obtains (with hats denoting relative changes):

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

This allows to isolate the elasticity of substitution $\rho = 1.66$. Now, (12) and (14) can be solved for the relative sectoral weights $\zeta = 0.73$ and $(1 - \zeta) = 0.27$ as well as the elasticities of aggregate output with respect to the sectoral intermediate output levels:

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

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

The productivity difference parameter across the two subaggregates is estimated from the respective value added data as $\chi = 1.26$. Similarly, we exploit the time series properties of value added in the two industrial subaggregates in order to parametrize the relevant stochastic processes for technology. We directly infer $\rho_a = 0.79$, $\rho_v = 0.66$ and $\rho_{av} = 0.67$; the volatility parameters $\sigma_a$ and $\sigma_v$ are also estimated from the relevant value added data, but adjusted (keeping relative values constant) to be consistent with the volatility of aggregate TFP, which yields $\sigma_a = 0.0075$ and $\sigma_v = 0.0111$. Finally, $\rho_j = 0.35$ and $\sigma_j = 0.0069$ are calibrated from the empirical process for $M2$.

**Data sources:**

- Section 3: CPI inflation and GDP deflator, real GDP, government and private investment shares are all from the Bureau of Economic Analysis (2006); the own rate of M2 and Moody's Seasoned Aaa Corporate Bond Yield are from the Federal Reserve Bank of St. Louis (2006); the financial controls are from Beck and Levine (1999).
- Section 6.1: The growth rate of value added at 3-digit SIC level is from the UNIDO (2002) industrial statistics database - the data are identical to the OECD-STAN (2003) data for the US; the other data sources are as for Section 3.
- Section 6.2: The firm-level data employed on top of the aggregate data come from the Compustat database; apart from the larger period of time covered, they coincide with the data employed by Opler et al. (1999).

Table 1: US aggregate quarterly and yearly data: Inflation & TFP-growth

**unrestricted VAR**

| | quarterly | yearly | | quarterly | yearly |
|---|---|---|---|---|---|
| **dependent variable: TFP-growth** | | | **dependent variable: inflation** | | |
| L.TFP-growth | -.0656 | .0806 | L.TFP-growth | -.0572 | -1.20** |
| | (-.56) | (.22) | | (-.93) | (-2.22) |
| L.inflation | -.1761** | -.2399*** | L.inflation | .8486*** | .8760*** |
| | (-2.24) | (-2.76) | | (20.68) | (6.81) |
| L.GDP-growth | -.0727 | -.2582 | L.GDP-growth | .0382 | 1.24*** |
| | (-.81) | (-1.12) | | (.82) | (3.64) |
| L.inv-share | -.1000*** | -.0231 | L.inv-share | .0289 | -.1244 |
| | (-2.61) | (-.13) | | (1.45) | (-.46) |
| **dependent variable: GDP-growth** | | | **dependent variable: inv-share** | | |
| L.TFP-growth | -.6108*** | .6148 | L.TFP-growth | -.5447*** | .5393 |
| | (-4.00) | (0.92) | | (-5.37) | (1.30) |
| L.inflation | -.2238** | -.2596 | L.inflation | .0543 | .0473 |
| | (-2.19) | (-1.62) | | (.80) | (.48) |
| L.GDP-growth | .6053*** | -.3055 | L.GDP-growth | .5528*** | -.0866 |
| | (5.23) | (-.72) | | (7.19) | (-.33) |
| L.inv-share | -.1335*** | -.0479 | L.inv-share | .8149*** | .5862*** |
| | (-2.69) | (-.14) | | (24.72) | (2.83) |

**Granger causality test**

| | quarterly | yearly | | quarterly | yearly |
|---|---|---|---|---|---|
| **dependent variable: TFP-growth** | | | **dependent variable: inflation** | | |
| inflation | 0.025** | 0.006*** | TFP-growth | 0.351 | 0.026** |
| GDP-growth | 0.415 | 0.262 | GDP-growth | 0.412 | 0.000*** |
| inv-share | 0.009*** | 0.899 | inv-share | 0.147 | 0.643 |
| **dependent variable: GDP-growth** | | | **dependent variable: inv-share** | | |
| TFP-growth | 0.000*** | 0.360 | TFP-growth | 0.000*** | 0.195 |
| inflation | 0.028** | 0.105 | inflation | 0.423 | 0.634 |
| inv-share | 0.007*** | 0.886 | GDP-growth | 0.000*** | 0.742 |

**Lag length selection criteria**

| | | | | |
|---|---|---|---|---|
| quarterly | 167 Observations | AIC: 4. lag | HQIC: 1. lag | SBIC: 1. lag |
| yearly | 30 Observations | AIC: 1. lag | HQIC: 1. lag | SBIC: 1. lag |

We exclusively report the effects on TFP-growth. Always include a constant. 1960:1 - 2001:4 quarterly and 1970-2000 yearly data. Endogenous variables: inflation, GDP-growth, private investment share. Heteroscedasticity-robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%. Test statistics are reported in p-values.

Table 2: US aggregate yearly data: Inflation, corporate interest rates, investment composition, corporate liquidity & TFP-growth

| | TFP-growth | | | *first stage*[1)] R&D/assets | TFP-growth | | | *first stage*[1)] liquidity/assets |
|---|---|---|---|---|---|---|---|---|
| | OLS | GMM-IV | GMM-IV | OLS | OLS | GMM-IV | GMM-IV | OLS |
| R&D/assets | 2.04*** | 1.69*** | 2.66*** | | | | | |
| | (2.76) | (2.92) | (2.99) | | | | | |
| liquidity/assets | | | | | .7279** | 1.13*** | 1.27* | |
| | | | | | (2.53) | (2.74) | (1.94) | |
| L.inflation | | | | -.0604*** | | | | -.1643*** |
| | | | | (-3.20) | | | | (-3.07) |
| assets | -.0045 | | -.0030 | .0022*** | -.0040 | | -.0053 | .0048** |
| | (-.96) | | (-.83) | (2.71) | (-.77) | | (-.98) | (2.09) |
| oper. income | -.0145 | | -.0023 | .0050 | -.0074 | | -.0005 | .0015 |
| | (-.63) | | (-.16) | (1.33) | (-.73) | | (-.05) | (.16) |
| long-debt | .0273 | | .0108 | -.0128*** | .0257 | | .0281 | -.0277*** |
| | (1.45) | | (.80) | (-3.12) | (1.19) | | (1.61) | (-3.30) |
| inv-share | .1792 | | | | .1083 | | | |
| | (.89) | | | | (.61) | | | |
| gov-share | -1.61* | | | | -1.39 | | | |
| | (-1.91) | | | | (-1.36) | | | |
| Observations | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| 1. serial-cor. | .466 | .464 | .875 | .219 | .985 | .495 | .565 | .065 |
| 2. serial-cor. | .464 | .503 | .346 | .328 | .826 | .318 | .447 | .620 |
| Hansen-test | - | .694 | .315 | - | - | .742 | .573 | - |

1) We exclusively show the results of the first stage regression for the first lag of inflation; the correlation coefficient between inflation and corporate interest rates is 0.42.

Exog. variables (IVs): first and second lags of inflation and interest rates (Moody's Seasoned Aaa Corporate Bond Yield).

Additional exogenous control variables in the 1. and 2. stage for robustness check:

corporate assets, corporate operating income, corporate long-run debt, corporate interest expenditures.

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

Null-hypothesis of well-specified model. Test statistics are reported in p-values.

Always include a constant. 1970 - 2000 yearly data.

Table 3: US aggregate quarterly data: Inflation, corporate interest rates, investment composition, corporate liquidity & TFP-growth

| | TFP-growth | | | *first stage*[1)] R&D/assets | TFP-growth | | | *first stage*[1)] liquidity/assets |
|---|---|---|---|---|---|---|---|---|
| | OLS | GMM-IV | GMM-IV | OLS | OLS | GMM-IV | GMM-IV | OLS |
| R&D/assets | .5308** | .8768* | 1.01* | | | | | |
| | (2.22) | (1.73) | (1.81) | | | | | |
| liquidity/assets | | | | | -.0025 | .0365 | .0481 | |
| | | | | | (-.04) | (1.05) | (1.26) | |
| L.inflation | | | | -.1861*** | | | | -2.95*** |
| | | | | (-2.87) | | | | (-4.08) |
| assets | .0001 | | .0006 | -.0002 | .0001 | | -.0002 | .0120*** |
| | (.08) | | (.44) | (-.51) | (.04) | | (-.11) | (2.87) |
| oper. income | -.0096 | | -.0207* | .0151*** | -.0034 | | -.0045 | -.0223 |
| | (-.86) | | (-1.94) | (3.71) | (-.29) | | (-.47) | (-.64) |
| long-debt | .0010 | | .0006 | -.0006 | .0009 | | .0029 | -.0692*** |
| | (.18) | | (.10) | (-.34) | (.16) | | (.46) | (-3.57) |
| inv-share | -.0004 | | | | -.0001 | | | |
| | (-.56) | | | | (-.13) | | | |
| gov-share | .0052 | | | | .0028 | | | |
| | (.70) | | | | (.39) | | | |
| Observations | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 1. serial-cor. | .303 | .358 | .331 | .174 | .551 | .318 | .325 | .405 |
| 2. serial-cor. | .869 | .407 | .369 | .069 | .930 | .333 | .646 | .011 |
| Hansen-test | - | .482 | .555 | - | - | .485 | .490 | - |

1) We exclusively show the results of the first stage regression for the first lag of inflation; the correlation coefficient between inflation and corporate interest rates is 0.55.
Exog. variables (IVs): first and second lags of inflation and interest rates (Moody's Seasoned Aaa Corporate Bond Yield).
Additional exogenous control variables in the 1. and 2. stage for robustness check:
corporate assets, corporate operating income, corporate long-run debt, corporate interest expenditures.
Heteroscedasticity-robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.
Null-hypothesis of well-specified model. Test statistics are reported in p-values.
Always include a constant. 1960:1 - 2001:4 quarterly data.

Table 4: Calibrated parameter values

| $\beta$ | $\sigma$ | $\mu$ | $\gamma$ | $\alpha^k$ | $\alpha^z$ | $\delta$ | $\theta$ | $\phi$ | $\Omega$ | $\chi$ | $\eta$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.98 | 2 | 0.167 | 0.0037 | 0.31 | 0.31 | 0.0112 | 0.25 | 12.5 | 0.95 | 1.26 | 0.97 |
| $\zeta$ | $\rho$ | $\rho_a$ | $\sigma_a$ | $\rho_v$ | $\sigma_v$ | $\rho_{av}$ | $\rho_j$ | $\sigma_j$ | $b$ | $\mu_\xi$ | $\sigma_\xi$ |
| 0.73 | 1.66 | 0.79 | 0.0075 | 0.66 | 0.0111 | 0.67 | 0.35 | 0.0069 | 0.15 | -0.75 | 0.75 |

Table 5: Cyclical statistics, variance decomposition and contemporaneous correlations

| Variable | US econ. | benchm. econ. | $\sigma_j = 0$ | % change1) | $\sigma_j = 0$ $\theta = 0.05$ | % change2) | US econ. | benchm. econ. | $\sigma_j = 0$ | $\theta = 0.05$ | $\sigma_j = 0$ $\theta = 0.05$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | standard deviation (%) | | | | | | contemp. corr. with real output (GDP) | | | | |
| GDP | 1.54 | 1.20 | 1.19 | 0.83 | 1.19 | 2.46 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| HOURS | 1.74 | 2.12 | 1.66 | 21.70 | 1.66 | 41.34 | 0.88 | 0.33 | 0.38 | 0.31 | 0.38 |
| INV | 5.60 | 5.61 | 5.59 | 0.36 | 5.59 | 1.41 | 0.93 | 0.71 | 0.71 | 0.71 | 0.72 |
| $\tilde{R}\,(\mathrm{M2})$ / $\tilde{R}^{corp}$ | 0.63 / 0.68 | 1.53 | 0.04 | 97.72 | 0.08 | 97.03 | 0.24 / −0.17 | 0.07 | 0.00 | 0.13 | 0.00 |
| $\Delta$ M2 | 0.69 | 0.67 | 0.00 | 100.00 | 0.00 | 100.00 | -0.30 | -0.10 | 0.00 | -0.16 | 0.00 |
| $\pi\,(\mathrm{dGDPdef})$ / $\pi\,\mathrm{dCPI}$ | 0.29 / 0.33 | 1.29 | 1.09 | 15.50 | 1.07 | 20.74 | 0.14 / 0.28 | -0.28 | -0.31 | -0.26 | -0.31 |
| TFP | 0.81 | 1.34 | 1.11 | 17.16 | 1.12 | 34.88 | 0.58 | 0.55 | 0.73 | 0.36 | 0.73 |
| | | | | | | | contemp. corr. with nom. interest rates $[\tilde{R}(\mathrm{M2})/\tilde{R}^{corp}]$ | | | | |
| TFP | | | | | | | −0.29 / −0.44 | -0.53 | 0.15 | -0.74 | 0.12 |
| | | | | | | | contemp. corr. with inflation $[\pi\,(\mathrm{dGDPdef})/\pi\,(\mathrm{dCPI})]$ | | | | |
| TFP | | | | | | | −0.35 / −0.22 | 0.01 | -0.27 | -0.02 | -0.27 |

1) Percentage change due to shutting down money shocks in benchmark economy (column two vs. column three).

2) Percentage change due to shutting down money shocks in economy with $\theta = 0.05$ (not reported vs. column five).

All series except nominal interest rates and inflation are in logs. All series have been Hodrick-Prescott filtered with a smoothing parameter of 1600. Empirical statistics are based on US quarterly data 1964:1-2006:2. Nominal interest rates are measured by the own rate on $M2$ ($\tilde{R}\,(M2)$) and the yield on corporate bonds (Moody's Seasoned Aaa Corporate Bond Yield) ($\tilde{R}^{corp}$), inflation by changes in the GDP deflator ($\pi\,(dGDPdef)$) and the consumer price index ($\pi\,(dCPI)$), respectively, monetary aggregates by $M2$. Note that the model economy does not distinguish neither between $\tilde{R}\,(M2)$ and $\tilde{R}^{corp}$ nor between ($\pi\,(dGDPdef)$) and ($\pi\,(dCPI)$).

Table 6: Steady state values and selected contemporaneous correlations

| Variable | Friedman rule $\pi^* = -2.42$ | $mg^* = (1+\gamma)$ $\pi^* = 0.00$ | $mg^* = 1.0167$ $\pi^* = 1.31$ | $mg^* = 1.05$ $\pi^* = 4.74$ | $mg^* = 1.1$ $\pi^* = 10.11$ | $mg^* = 1.2$ $\pi^* = 21.69$ |
|---|---|---|---|---|---|---|
| $\tilde{R} - 1$ | 0.0000 | 0.0248 | 0.0383 | 0.0734 | 0.1284 | 0.2471 |
| $z/k$ | 0.1450 | 0.1413 | 0.1393 | 0.1344 | 0.1271 | 0.1132 |
| $d$ | 0.0359 | 0.0336 | 0.0325 | 0.0297 | 0.0260 | 0.0197 |
| $d/y$ | 0.0921 | 0.0897 | 0.0887 | 0.0857 | 0.0815 | 0.0730 |
| $d/(d + \theta wL)$ | 0.3700 | 0.3658 | 0.3637 | 0.3578 | 0.3497 | 0.3314 |
| $G$ | 0.8414 | 0.8330 | 0.8285 | 0.8165 | 0.7975 | 0.7563 |
| $y^z/y^k$ | 0.1537 | 0.1483 | 0.1455 | 0.1381 | 0.1276 | 0.1077 |
| $\mathcal{T}$ | 0.9712 | 0.9672 | 0.9650 | 0.9593 | 0.9506 | 0.9321 |
| $\rho(\tilde{R}, \mathcal{T})$ | -0.49 | -0.52 | -0.53 | -0.55 | -0.57 | -0.61 |

Statistics generated from simulated and Hodrick-Prescott filtered (smoothing parameter 1600) series for the benchmark economy.

Table 7: USA: Sectoral volatility and mean of growth in value added

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

Table 8: US sectoral yearly data:
Inflation-sensitivity with respect to volatility and mean of growth rate of value added

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

The correlation coefficient between the volatility- and mean rankings amounts to 0.23 (s.e. 0.03) according to Spearman's rank correlation test.
1963-2000 yearly data. Always include a constant. Heteroscedasticity- and serial correlation robust s.e. t-statistics in parenthesis. ***,**,* significant at 1%, 5%, 10%.

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

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

1) The IV-matrix starts at the 4. lag since Hansen-test indicates that 2. and 3. lag endogenous.
Firm-level data on R&D expenses, corporate liquidity and total assets all measured in millions of US$.
1989:1-2000:4 quarterly data. Heteroscedasticity- and serial correlation robust s.e. t-statistics in parenthesis.
***,**,* significant at 1%, 5%, 10%.

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

| | Corporate liquidity | | R&D expenses per firm | | | | $spdrc < 12$ | $spdrc \geq 12$ |
|---|---|---|---|---|---|---|---|---|
| | GMM-sys | GMM-sys | GMM-dif | GMM-dif | GMM-sys | GMM-sys[1)] | GMM-sys | GMM-sys |
| inflation | -1.38** | | -.4707* | -.3764* | | | -3.721* | -22.514** |
| | (-2.32) | | (-1.73) | (-1.68) | | | (-1.72) | (-2.16) |
| yield-corp-bonds | | -1.61** | | | -.0366 | .0889 | | |
| | | (-2.34) | | | (-.34) | (.88) | | |
| corp. liquidity | | | | .0353*** | | .0486*** | | |
| | | | | (4.15) | | (4.20) | | |
| assets | .0230** | .0231** | .0035** | .0021 | .0007 | -.0010 | -.0014 | -.0008 |
| | (2.23) | (2.25) | (2.18) | (1.48) | (-1.19) | (-1.57) | (-.74) | (-.24) |
| spdrc | | | | | | | -99.1 | -439.3** |
| | | | | | | | (-1.24) | (-2.09) |
| lag-dep.-var. | .7361*** | .7357*** | .8504 | .8237 | 1.01 | .9462 | .1.00 | .9289 |
| | (7.73) | (7.77) | (19.08) | (17.73) | (29.43) | (21.00) | (14.69) | (7.52) |
| Firms | 10903 | 10923 | 9705 | 9703 | 9742 | 10925 | 378 | 492 |
| Observations | 83468 | 84277 | 72009 | 71981 | 84355 | 84314 | 6217 | 5194 |
| 1. auto-cor. | .002 | .002 | .001 | .002 | .001 | .001 | .017 | .182 |
| 2. auto-cor. | .468 | .488 | .604 | .554 | .616 | .533 | .519 | .474 |
| Hansen-test | .238 | .260 | - | - | .075 | .267 | 221 | .274 |

1) The IV-matrix starts at the 4. lag since Hansen-test indicates that 2. and 3. lag endogenous.
Firm-level data on R&D expenses, corporate liquidity and total assets all measured in millions of US$.
1970-2000 yearly data. Heteroscedasticity- and serial correlation robust s.e. t-statistics in parenthesis.
***,**,* significant at 1%, 5%, 10%.

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