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Abstract

We study the causes behind the shift in the U.S. economy's trend following the Great Recession. To this end, we propose a model featuring endogenous productivity á la Romer and a financial friction á la Kiyotaki-Moore. Adverse financial disturbances during the recession and the lack of strong tailwinds post crisis resulted in a severe contraction and the downward shift in the economy's trend. Had financial conditions remained stable during the crisis, the economy would have grown at its average growth rate. From a historical perspective, the Great Recession was unique because of the size and persistence of adverse shocks, and the lackluster performance of favorable shocks since 2010.

1 Introduction

A few years into the recovery from the Great Recession, it is becoming clear that real GDP is failing to recover. Namely, the economy is growing at pre-recession growth rates, but the crisis seems to have impinged a shift upon output. Figure 1 shows the level and growth rate of real GDP over the past decade. Without much effort, one can see that the economy is moving along a (new) trend that lies below the one prevailing in 2007,[1] which we extend into the future to highlight a scenario in which the economy never returns to the original trend.[2] With its economic significance, it is not surprising that this tepid recovery has spurred debate about causes and consequences of

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[1] More formally, the shift in the GDP trend is detected by the flexible estimation of trends with regime shifts recently advanced by Eo and Kim (2012). We thank Yunjong Eo for helping with the estimation using their approach.

[2] The forecast is built assuming that the economy will be growing at the average growth rate for the period 2009.Q2 - 2015.Q1.

this "macroeconomic disaster" (Hall (2014)).[3] An emerging consensus among economic observers is that, to some degree, the Great Recession was exacerbated by financial shocks (Brunnermeier, Eisenbach, and Sannikov (2012); Christiano, Motto, and Rostagno (2014); and Stock and Watson (2012)). More precisely, the financial turmoil following the collapse of Lehman Brothers in 2008 has often been blamed for the depth and length of the recession and the subsequent sluggish recovery.[4] We contribute to this literature by proposing a structural model with financial frictions, financial shocks, and endogenous productivity, thereby shedding light on the causes behind the shift in the trend of U.S. GDP.

We introduce endogenous productivity for the following reasons. First of all, shocks in a prototypical real business cycle (RBC) model exhibit exclusively short-run dynamics; i.e., the economy always reverts back to its pre-shock trend. This is an unpleasant feature to study a shift in the trend. Some obvious modifications to an RBC model for introducing a shift in the trend are not satisfactory either. Namely, augmenting it with a permanent shift in financial conditions is at odds with the data because different financial indicators, such as liquidity, spreads, or lending activity, have recovered since the end of the crisis.[5] Augmenting it with an exogenous break in productivity around the crisis is rather mechanical. Moreover, this alternative excludes the interesting possibility that the financial crunch is a cause of the shift in the trend. These considerations lead us to construct an alternative, more flexible model in which all structural shocks have the potential to influence the trend.

The model is based on the framework of Romer (1990). In the model, investment in research and development leads to the creation of new intermediate goods. A final goods producer takes these inputs to manufacture goods that are consumed and used for investment. Knowledge spillover sustains growth in the long run. The second key element in our model is a financial friction like the one in Kiyotaki and Moore (2012). Entrepreneurs fund their projects through asset markets, which are subject to shocks altering the liquidity of equity. In their formulation, a drop in liquidity reduces the availability of funds to finance new projects, leading to a contraction in investment. In our model, this lack of funding leads to a low level of innovative activities, to weak knowledge

[3] See a debate in economic blogs, like those maintained by John Cochrane, John Taylor, and Stephen Williamson. A more provocative argument that declares the end of growth in the U.S. has been advanced by Robert Gordon (Why Innovation Won't Save Us. The Wall Street Journal, December 21, 2012).

[4] Financial markets were unusually tight. According to the survey of senior loan officers, lending standards tightened in the aftermath of Lehman Brothers' collapse. The spread between loan rates and the banks' cost of funding spiked in 2008. The aggregate stock of bank credit dramatically shrank during the Great Recession (Becker and Ivashina (2014)). Empirical studies using micro data support that the dramatic shrinkage in lending activities was largely driven by an exogenous reduction in credit (Almeida, Campello, Laranjeira, and Weisbenner (2009); Duchin, Ozbas, and Sensoy (2010); and Campello, Graham, and Harvey (2010)). Giroud and Mueller (2015) find that high-leveraged firms had to reduce employment, close down establishments, and cut back on investment, most likely because they were financially constrained. A detailed discussion on these empirical results is in the appendix.

[5] Other economic factors might cause a permanent change in the resource allocation. Among many possibilities, we find changes in labor market conditions most interesting. See Hall (2014) for empirical facts, and Nakajima (2012) for an interesting quantitative analysis. Our focus on productivity and financing channels is not exclusionary to the analysis focusing on the labor market. We view our study as complementary to this interesting literature.

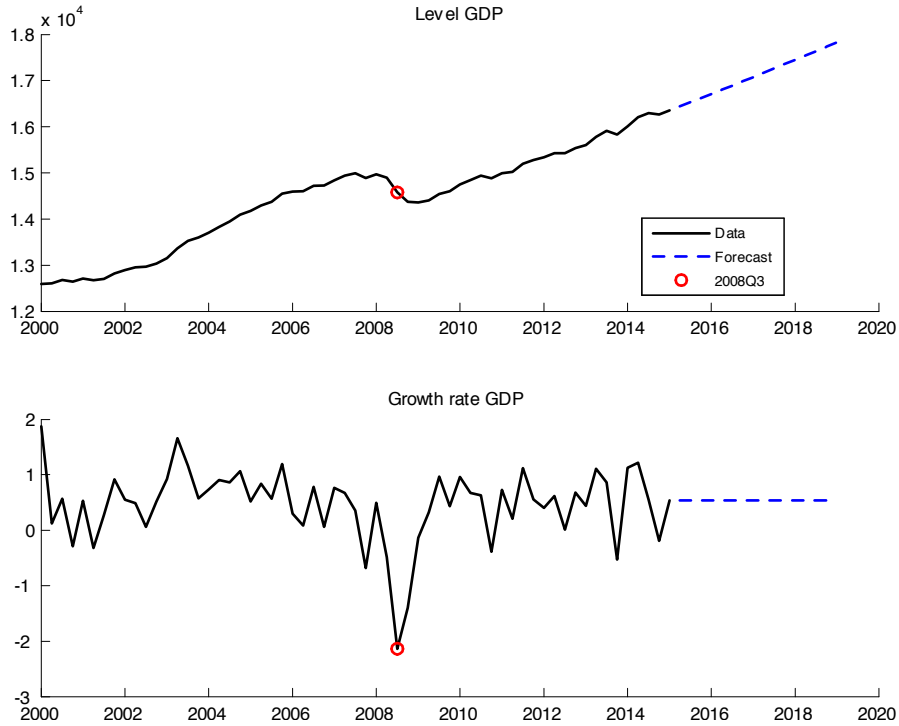

Figure 1: U.S. Real GDP

spillover, and, hence, to a downward shift in the economy's trend.

With our proposed model in hand, we read the recent history of the U.S. economy. Specifically, we use data on economic activity including measures of liquidity, productivity, and the stock market to estimate our structural model. The estimation delivers several key insights. To begin with, we find that the estimated model is capable of generating a boom in both the economy and the stock market following a favorable liquidity innovation. This is in great contrast to previous research, in which a loosening of the financial constraint tends to decrease both consumption and the stock market value (Kiyotaki and Moore (2012) and Shi (2015)). We overcome this counterfactual prediction by exploiting a unique feature of our model; temporary liquidity shocks can shift the trend in our model while their impacts are limited to transitory fluctuations around the trend in previous research. In other words, "the cycle" after a financial innovation "is the trend" in our model.[6] This realization enables us to connect our work to two important papers in distinct literatures. One is Jaimovich and Rebelo (2009) in the news shock literature, who use a suitably modified RBC model to study news shocks. In their model, a signal informing agents that technology will undergo a permanent rise at some point in the future (a news shock) causes an immediate economic boom. The other paper is Bansal and Yaron (2004) in the long-run risk literature in finance, who establish the condition

[6]We thank Nobu Kiyotaki for pointing out the similarity between financial crises in developed economies and emerging markets' business cycles which Aguiar and Gopinath (2007) famously describe as "the cycle is the trend." For the empirical support of permanent effects of financial crises, see Cerra and Saxena (2008).

under which a shock to both consumption growth and dividend growth causes an immediate stock market boom. Because liquidity shocks in our model are similar to both news shocks and long-run risks, we incorporate many of the insights of the aforementioned papers into the model; as a result, liquidity shocks generate a boom in both the economy and the stock market. Furthermore, we find that liquidity shocks are identified as an important driver of business cycles. According to our estimation, these shocks account for about a quarter of the volatility of output growth and nearly one fifth of the volatility of the growth rates of consumption and investment.

We also find that the liquidity friction is by itself a shock amplification mechanism. The point is most vividly seen in the economy's response to government shocks. Specifically, a reduction of transfers to entrepreneurs from the government leads to a recession in our model. Because the economy's ability to efficiently allocate funds among agents (workers and entrepreneurs) is limited due to a weak financial market, a reduction in entrepreneurs' income leads to a slowdown in innovative activities, thereby slowing down the economy.

Our estimated model provides a lively description of the events before, during, and after the Great Recession. Chief among these findings is that the crisis was caused by unfavorable shocks to liquidity and government transfers because they choked innovative activities. Specifically, entrepreneurial projects were not funded partly because external financing (cashing out assets in our model) was difficult, and partly because internal resources (entrepreneurs' income) sharply declined. Although technology and preference shocks were tailwinds during the crisis, they were not strong enough to offset the aforementioned headwinds. By using shock decompositions and counterfactual scenarios, we uncover that improving financial markets as captured by favorable liquidity and marginal efficiency of investment shocks was critical in pushing the economy out of the recession. However, these beneficial factors were insufficient to pull the economy above its average growth rate, resulting in the break in trend we discussed. This finding is in sharp contrast with previous recessions. For example, we find that in spite of the prolonged crisis in the early 1980s, a sequence of favorable innovations between the end of 1982 and 1985 brought the economy back to its pre-crisis trend. A similar pattern arises in other recent recessions.

We also read the U.S. data through the lens of two variants of our model. One is a standard real business cycle model augmented with our financial friction and exogenous non-stationary productivity. The other is our endogenous growth model without the financial friction. In great contrast to the benchmark model, exogenous shocks to productivity are an essential player accounting for almost half of the volatility of output growth in these models. The Great Recession is driven to a large extent by productivity. Liquidity plays a very modest role, and so does government consumption. Measurement errors rather than structural shocks account for bulk of volatilities in the stock market value and TFP.

Our work is broadly consistent with some recent empirical work. We agree with Hall (2014) not only that a shortfall in TFP is a key contributor to a shortfall in output during the Great Recession, but also that the crisis might cause the shortfall in TFP as well. He raises a concern that the size of

the shortfall in TFP is not very large relative to its standard deviation, but we think that a secular movement in TFP is also important. Christiano, Eichenbaum, and Trabandt (2015) document that TFP is persistently low during the Great Recession, and as of this writing, there is no sign of a reversal in this trend. Our estimated model implies that agents in the economy had foreseen it before the end of our sample (2011.Q4), and this pessimistic view exacerbated the recession.

Our paper provides an interesting and new perspective on the dynamics of TFP. From our estimation exercise we learn that the initial slowdown in TFP in the mid-2000s reported by Fernald (2014) was caused by exogenous disturbances to technology.[7] Furthermore, the dismal growth in TFP in the late-2000s was driven by liquidity and government consumption shocks. In the earlier period, adverse shocks were counterbalanced by other structural shocks. But such fortunate draws did not last long, resulting in the sharp slowdown in TFP growth in the later period (Figure 2).

Consistent with our estimates, measures of innovative activities indeed slowed down during the Great Recession. Figure 2 plots R&D, patent applications, and TFP over the last four decades.[8] To facilitate comparison, we remove trend components.[9] Slowdowns in innovative activities in recent years are apparent. Moreover, innovative measures and TFP are correlated as documented in an extensive literature.[10] Using a forecasting regression, we find that a 1 percentage point drop in R&D predicts a drop of 9.7 basis points in TFP over a six year horizon.[11] Because R&D has sharply declined since 2007, the regression implies that people become more and more pessimistic about the future productivity during this critical period.[12] We find a similar result using the patent application data. While the analysis is simple, we take the result as a supporting evidence for the basic mechanism in our model. In the appendix, we provide additional information on a slowdown in firm entries.

A related and important channel in our model is that entrepreneurs/firms need funding to innovate. In reality, this funding often comes from Private Equity firms (PE), particularly those specialized in venture (growth) capital. We find informative that global investment by PEs collapsed

[7] Following Christiano, Eichenbaum, and Trabandt (2015) and Hall (2014), we mostly focus on the raw productivity measure instead of the utilization adjusted one in the following discussion.

[8] TFP data are taken from Fernald (2014); R&D is measured by real private investment in intellectual property products taken from the Bureau of Economic Analysis; patent data are those applied to utility patents in a calender year, taken from the U.S. Patent and Trademark Office.

[9] We assume a linear trend in the growth rates, and also assume that the levels of the variables are on the trend in 1970.

[10] Comin and Gertler (2006) report that R&D and TFP are strongly correlated in the U.S, and moreover, R&D leads TFP at a low frequency. Using R&D expenditure data from NSF and Compustat, Barlevy (2007) finds a positive correlation between R&D growth and GDP growth (0.49 for Compustat and 0.39 for NSF). Griliches (1990) in turn finds that R&D expenditures and the number of patents are correlated over time within firms. Kung and Schmid (2015) also find that R&D predicts productivity growth, output growth, and consumption growth.

[11] The regression equation is $\Delta tfp_{t,t+1} + \cdots + \Delta tfp_{t+5,t+6} = \alpha + \beta s_t + v_{t,t+6}$ where $\Delta tfp_{t,t+1}$ denotes the growth rate of TFP and s_t denotes R&D in logarithm. We use the data plotted in Figure 2. For an application of similar regressions, see Bansal and Yaron (2004), Jinnai (2015), and Kung and Schmid (2015).

[12] A 14.5 percentage point drop in R&D between 2007 and 2013 implies that people in 2013 forecast TFP growth over a six year horizon (between 2013 and 2019) to be 1.4 percentage point weaker than people in 2007 had forecast over the same horizon window (between 2007 and 2013). This result assumes that people base their forecast on the same regression equation.

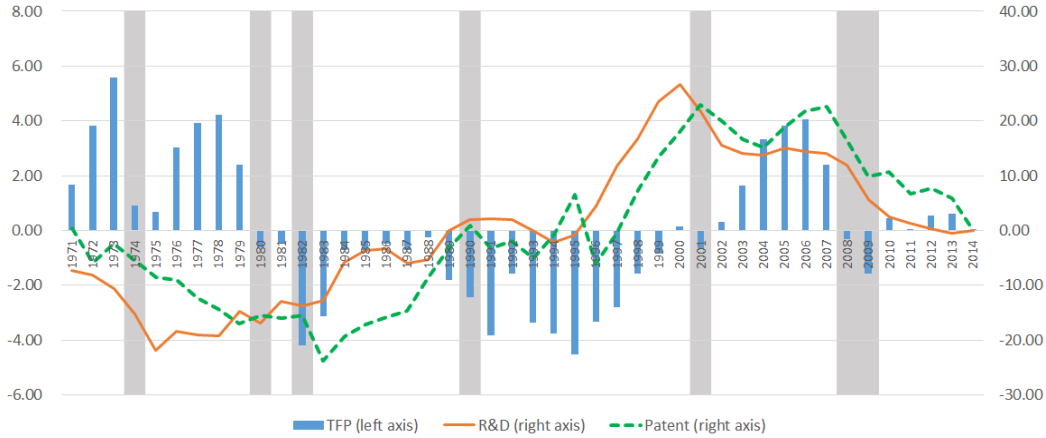

Figure 2: TFP, R&D, and Patent Applications

in 2008, reached a cyclical low in 2009 and remained flat between 2010 and 2012 (Bain and Company (2014)).[13] A similarly dare picture arises from data on exits by PEs or funds raised by PEs. These observations should be cautiously interpreted because information on different components of private equity investment, particularly that by venture capital firms, is rather scant. However, data from funds raised by venture-capital PE firms show a substantial decline post-2008. Indeed, fund-raising remained flat between 2010 and 2012 and below its cyclical peak. Overall, we view this industry-based data as suggestive of funding headwinds faced by entrepreneurs during and after the Great Recession.

Our paper relates to several branches in macroeconomics. The first one comes from the literature on endogenous growth with seminal contributions by Romer (1990), Grossman and Helpman (1991), and Aghion and Howitt (1997). Our use of Romer's endogenous growth model does not mean that our results crucially depend on this model's unique structure. Results similar to those discussed next should follow from other versions of endogenous growth models too.

Our analysis of the recent financial crisis brings us close to the literature on financial frictions in dynamic stochastic setups such as Bernanke, Gertler, and Gilchrist (1998), Jermann and Quadrini (2012), Kiyotaki and Moore (1997), and more recently, Del Negro, Eggertsson, Ferrero, and Kiyotaki (2011) and Kiyotaki and Moore (2012). Our use of Kiyotaki and Moore's liquidity model does not mean that many important aspects of the financial crisis such as mortgage defaults and idiosyncratic risk at the firm level are unimportant. We view our work as complementary to the studies focusing on these other aspects that are not directly captured by the liquidity model.

The empirical treatment used in our paper relates to the extensive literature on the estimation of dynamic stochastic general equilibrium models (Fernandez-Villaverde, Guerron-Quintana, and Rubio-Ramirez (2010) and Guerron-Quintana (2010)). Ajello (2014) is especially close. He

[13] We thank an anonymous referee for mentioning the Bain's report on private equity.

estimates a model with financial frictions in which competitive financial intermediaries transfer resources between entrepreneurs with heterogenous skills. His estimated model, like ours, is capable of generating a boom in both the economy and the stock market following a favorable financial shock, but the mechanisms are different. That is, while he shows that short-run shock amplification mechanisms such as nominal wage rigidities and endogenous quality distribution of investments are important in his stationary model, we show that endogenous growth is an alternative approach to induce co-movement.

Finally, we borrow ideas from the unified treatment of business cycles and long-term dynamics in Comin and Gertler (2006), Comin, Gertler, and Santacreu (2008), Gornemann (2014), Kung and Schmid (2015), and Saffie and Ates (2013). Relative to Comin and Gertler's pioneering work, we modify the households' side so that we can discuss financial frictions as well as feedback from the medium-frequency components to the high-frequency components. Queralto (2015) introduces financial frictions to Comin and Gertler (2006). Remarkably, a calibrated version of his small open economy model is capable of replicating the behavior of the South Korean economy following the 1997 crisis well even though he simulates the crisis event with exogenous shocks to the country's borrowing premium. We see that our paper is complementary to his not only because of differences in both motivations and models, but because we estimate our model instead of calibrating it. This difference is important because, as both Queralto and we find, the financial friction itself is a strong shock amplification mechanism potentially altering propagations of non-financial shocks. Because our Bayesian methods give different shocks a chance to account for the data, our finding further underscores the prominence of financial factors that Queralto finds in his calibrated model for a small open economy.

The rest of the paper is organized as follows. The next section outlines the model and discusses equilibrium conditions. Our empirical strategy is discussed in Section 3. Main results are in Section 4. The last section provides some concluding remarks.

2 Model

We describe our baseline model in two steps. First, we flesh out the household side where the financial friction takes place. Then we switch to the endogenous growth part of the model, which is primarily concentrated on the firm side of the economy.[14]

2.1 Household

The economy is populated by a continuum of households with measure one. Each household has a unit measure of members. At the beginning of the period, all members of a household are identical

[14] Our implementation of Kiyotaki and Moore's financial friction is taken from Shi (2015). The production side of the economy is taken from Kung and Schmid (2015).

and share the household's assets. During the period, the members are separated from each other, and each member receives a shock that determines the role of the member in that period. A member will be an entrepreneur with probability $\sigma_e \in [0,1]$ and a worker with probability $\sigma_w \in [0,1]$. They satisfy $\sigma_e + \sigma_w = 1$. These shocks are *iid* among the members and across time.

A period is divided into five stages: household's decisions, production, innovation (R&D), consumption, and investment. In the stage of household's decisions, all members of a household pool their assets: k_t units of physical capital and n_t units of equities. An equity corresponds to the ownership of a firm that is a monopolistic producer of a differentiated intermediate product. Aggregate shocks to exogenous state variables are realized. The capacity utilization rate u_t is decided. Because all the members of the household are identical in this stage, the head of the household evenly divides the assets among the members. The head of the household also gives contingency plans to each member, saying that if one becomes an entrepreneur, she spends s_t units of consumption goods for product development (R&D), consumes c_t^e units of consumption goods, and makes necessary trades in the asset markets so that she returns home with k_{t+1}^e units of capital and n_{t+1}^e units of equities. If the member becomes a worker, she supplies l_t units of labor, consumes c_t^w units of consumption goods, prepare i_t units of investment goods, and makes necessary trades in the asset markets so that she returns home with k_{t+1}^w units of capital and n_{t+1}^w units of equities. After receiving these instructions, the members go to the market and will remain separated from each other until the investment stage.

At the beginning of the production stage, each member receives the shock whose realization determines whether the individual is an entrepreneur or a worker. Competitive firms produce consumption goods from capital service, labor service, and intermediate goods. Monopolistic firms produce intermediate goods from consumption goods; in other words, the production is roundabout. After production, a worker receives wage income, and an individual receives compensation for capital service and dividend income on equities. The government levies taxes on income, and hands out a lump-sum transfer to each member. Both a fraction $\delta(u_t)$ of capital and a fraction δ_n of products depreciate.[15] $\delta(\cdot)$ is convex in the rate of utilization: i.e., $\delta'(u_t) > 0$ and $\delta''(u_t) \geq 0$.

The third stage in the period is R&D where entrepreneurs seek financing and undertake product development projects. We assume that an entrepreneur can transform any amount s_t units of consumption goods into $\vartheta_t s_t$ units of new products. The product development efficiency ϑ_t is an endogenous variable (specified later), but individual households take it as given. Following Bilbiie, Ghironi, and Melitz (2012), we assume that a new product enters production in the period following invention.[16] With this assumption, equities of new products are traded at the same price as equities of (undepreciated) existing products that have already paid out dividends. Individuals trade assets to finance R&D and to achieve the portfolio of asset holdings instructed earlier by their households.

[15] δ_n is what Bilbiie, Ghironi, and Melitz (2012) call death shock. The assumption of exogenous exit is adopted for tractability.

[16] Comin and Gertler (2006) consider a more realistic adoption stage.

The asset markets close at the end of this sub-period.

In the consumption stage, a worker consumes c_t^w units of consumption goods and an entrepreneur consumes c_t^e units of consumption goods. Then, individuals return home. In the investment stage, the head of the household collects the investment goods prepared by workers and uses them as inputs for investment. The capital stock at the beginning of the next period is determined by the following equation:

$$k_{t+1} = \underbrace{\left[\sigma_e k_{t+1}^e + \sigma_w k_{t+1}^w\right]}_{\text{capital before the investment stage}} + \underbrace{\left(1 - \Lambda\left(\frac{i_t}{i_{t-1}}\right)\right)\sigma_w i_t}_{\text{capital added in the investment stage}} \tag{1}$$

where $\Lambda(\cdot)$ is the investment adjustment cost function given by $\Lambda\left(\frac{i_t}{i_{t-1}}\right) = \frac{\bar{\Lambda}}{2}\left(\frac{i_t}{i_{t-1}} - \gamma\right)^2$, where γ is the growth rate of the economy in the non-stochastic steady state.

The contingency plans must satisfy a set of constraints. First, the instructions to an entrepreneur have to satisfy the intra-period budget constraint:

$$\begin{aligned} &\underbrace{c_t^e + s_t + \underbrace{p_{n,t} n_{t+1}^e + p_{k,t} k_{t+1}^e}_{\text{gross asset purchases}}}_{\text{gross expenditure}} \\ = &\underbrace{\left(1 - \underbrace{\tau_p}_{\text{tax}}\right)\left(\underbrace{\Pi_t n_t}_{\text{dividend}} + \underbrace{u_t R_t k_t}_{\text{rental}}\right) + \underbrace{p_{n,t}(1-\delta_n) n_t + p_{k,t}(1-\delta(u_t)) k_t}_{\text{resale value}} + \underbrace{p_{n,t}\vartheta_t s_t}_{\text{IPO}} + \underbrace{\tau_{tr,t}}_{\text{transfer}}}_{\text{gross after-tax income}}. \end{aligned} \tag{2}$$

The left-hand side is the gross total expenditure, collecting bills on consumption, R&D, and gross asset purchases, with $p_{n,t}$ denoting the price of equity and $p_{k,t}$ denoting the price of capital, respectively. The right-hand side is the gross, after-tax total income, collecting dividend income, compensation for capital services, resale values of assets, the income from the (hypothetical) initial public offerings of new products the entrepreneur has just innovated, and lump-sum transfers from the government. As will become clear, these transfers capture other aspects of the financial sector affecting entrepreneurs' funding. A similar constraint applies to the worker:

$$\begin{aligned} &c_t^w + \frac{i_t}{\chi_t} + p_{n,t} n_{t+1}^w + p_{k,t} k_{t+1}^w \\ = &(1-\tau_p)(\Pi_t n_t + u_t R_t k_t) + p_{n,t}(1-\delta_n) n_t + p_{k,t}(1-\delta(u_t)) k_t + (1-\tau_l) W_t l_t + \tau_{tr,t}. \end{aligned} \tag{3}$$

τ_p and τ_l are tax rates to capital/equity income and labor income, respectively. Note that one unit of consumption goods is converted to χ_t units of investment goods. χ_t is an exogenous random variable, which we call the marginal efficiency of investment (M.E.I.) shock.

There are other, crucial constraints on asset trading. That is, an entrepreneur can sell at most a fraction θ of new equities for products she has just innovated but has to retain the rest by herself.

In addition, she can sell at most a fraction ϕ_t of both existing equities and existing capital to others in the asset markets but has to retain the rest by herself. Effectively, these constraints introduce lower bounds to equity holding and capital holding of an entrepreneur at the closing of the markets:

$$n_{t+1}^e \geq \underbrace{(1-\theta)\,\vartheta_t s_t}_{\text{new equities required to retain}} + \underbrace{(1-\phi_t)\,(1-\delta_n)\,n_t}_{\text{existing equities required to retain}} \tag{4}$$

and

$$k_{t+1}^e \geq \underbrace{(1-\phi_t)\,(1-\delta\,(u_t))\,k_t}_{\text{existing capital required to retain}} . \tag{5}$$

ϕ_t is an exogenous random variable representing shocks to asset liquidity.[17] Similar constraints apply to workers, but we omit them because they do not bind in the equilibrium. There are non-negativity constraints for u_t, s_t, c_t^e, l_t, i_t, c_t^w, n_{t+1}^w, and k_{t+1}^w, but we omit them too for the same reason.

We view the equity market and the capital market as collectively representing the financial system, because these markets, albeit in a highly stylized manner, connect investors (entrepreneurs) and capital providers (workers). In addition, as in the actual economy, our model's growth potential hinges on the efficiency of those markets to transfer funds. We use liquidity shocks to capture exogenous innovations originating in the financial sector.

Let q_t denote a vector of endogenous, individual state variables, i.e., $q_t = (n_t, k_t, i_{t-1})$. The head of the household chooses instructions to its members to maximize the value function defined as

$$v\,(q_t;\Gamma_t,\Theta_t) = \max\left\{\sigma_e \frac{(c_t^e)^{1-\frac{1}{\psi}}}{1-\frac{1}{\psi}} + \sigma_w \frac{\left[c_t^w + \frac{\varphi_t}{\omega}\,(\Psi_t)\,(1-l_t)^{\omega}\right]^{1-\frac{1}{\psi}}}{1-\frac{1}{\psi}} + \beta\mathbb{E}_t\left[v\,(q_{t+1};\Gamma_{t+1},\Theta_{t+1})\right]\right\} \tag{6}$$

subject to (1), (2), (3), (4), (5), and

$$n_{t+1} = \sigma_e n_{t+1}^e + \sigma_w n_{t+1}^w.$$

φ_t is an exogenous preference shock, that we assume is common across households. Γ_t is a vector of endogenous, aggregate state variables, i.e., $\Gamma_t = (N_t, K_t, I_{t-1})$, where N_t is the mass of products available in the economy, K_t is the capital stock in the economy, and I_{t-1} is the investment level in the previous period. Θ_t is a vector of exogenous state variables. To ensure a balanced growth equilibrium, we introduce a term Ψ_t to the worker's utility. Specifically, following Comin and Gertler (2006), we define it as $\Psi_t = p_{k,t}K_t$ and interpret it as the sophistication of the economy.

The utility function is in the class proposed by Greenwood, Hercowitz, and Huffman (1988). Following the lead of Benhabib, Rogerson, and Wright (1991), we interpret it as a reduced form preference over market quantities in the presence of home production. Specifically, we assume that

[17] Brunnermeier et al. (2012) refer to this type of liquidity as *market liquidity*. Since our model does not feature irreversibilities, physical and intangible capitals are also *technologically liquid*.

the worker's original preference is given by

$$\frac{\left[c_t^w + c_{n,t}^w\right]^{1-\frac{1}{\psi}}}{1-\frac{1}{\psi}}. \tag{7}$$

$c_{n,t}^w$ is consumption of nonmarket goods, which are individually produced by the production function defined as

$$c_{n,t}^w = \frac{\varphi_t}{\omega}\left(\Psi_t\right)\left(l_{n,t}\right)^{\omega},$$

where $l_{n,t}$ is hours of work in the nonmarket sector. Without utility from leisure, the time not used in the market sector is used for the production in the nonmarket sector. In addition, the environment does not permit intra-household sharing of nonmarket goods $c_{n,t}^w$. Therefore, with worker's time endowment normalized to be one, we find that the worker's utility function in (6) is a reduced form utility of (7). Note that a similar argument can be made to entrepreneurs. Namely, entrepreneur's original utility is similar to (7), but because they do not supply labor, their utility function is trivially reduced to the one in (6).

As in Shi (2015), we will restrict our attention to the case in which $1 < p_{n,t}\vartheta_t < 1/\theta$ always hold. The first inequality implies that R&D is a good business, because the marginal cost of product development is smaller than the marginal revenue of product development. The second inequality implies that the entrepreneur must pay a down payment, because the amount of product development costs that the entrepreneur can finance by issuing equities is smaller than the total costs. These two conditions jointly imply that an entrepreneur's liquidity constraints (4) and (5) must be binding at the optimum. See the appendix for a formal discussion.

The optimality condition for labor supply is

$$\varphi_t\left(\Psi_t\right)\left(1-l_t\right)^{\omega-1} = \left(1-\tau_l\right)W_t. \tag{8}$$

It equates the marginal rate of substitution to the after-tax wage rate.[18] The optimality condition for investment is

$$\frac{1}{\chi_t} = p_{k,t}\left(1-\Lambda\left(\frac{i_t}{i_{t-1}}\right)-\Lambda'\left(\frac{i_t}{i_{t-1}}\right)\frac{i_t}{i_{t-1}}\right)+\mathbb{E}_t\left[\beta\left(\frac{\mu_{t+1}^w}{\mu_t^w}\right)p_{k,t+1}\Lambda'\left(\frac{i_{t+1}}{i_t}\right)\left(\frac{i_{t+1}}{i_t}\right)^2\right],$$

where μ_t^w is the worker's marginal utility of consumption defined as $\mu_t^w = \left[c_t^w + \frac{\varphi_t}{\omega}\left(\Psi_t\right)\left(1-l_t\right)^{\omega}\right]^{-\frac{1}{\psi}}$. The optimality condition equates the costs and the benefits of investment.

The optimality condition for product developments is

$$\left(c_t^e\right)^{-\frac{1}{\psi}} = \left(\frac{\vartheta_t\left(1-\theta\right)}{1-\theta p_{n,t}\vartheta_t}\right)\beta\mathbb{E}_t\left[\frac{\partial v\left(q_{t+1};\Gamma_{t+1},\Theta_{t+1}\right)}{\partial n_{t+1}}\right]. \tag{9}$$

[18] Derivations of first-order optimality conditions are in the appendix.

The intuition is the following. An entrepreneur can increase the utility by consuming the last unit of her disposable income (the left-hand side). If, however, she devotes the same resource to product development, she can create $\vartheta_t / (1 - \theta p_{n,t} \vartheta_t)$ units of new products, which is the efficiency of converting consumption goods to new products multiplied by the reciprocal of the down payment. Among the developed products, a fraction $(1 - \theta)$ is unsold in the market and therefore added to the household's asset portfolio. Because each equity is worth $\beta \mathbb{E}_t \left[\partial v \left(q_{t+1}; \Gamma_{t+1}, \Theta_{t+1}\right) / \partial n_{t+1}\right]$ to the household, the right-hand side is the expected benefit of product development. The condition says that these two uses of a resource should be indifferent at the margin. We also find

$$\beta \mathbb{E}_t \left[\frac{\partial v \left(q_{t+1}; \Gamma_{t+1}, \Theta_{t+1}\right)}{\partial n_{t+1}}\right] = \mu_t^w p_{n,t},$$

implying that workers are indifferent between consumption and purchasing an equity at the margin. Substituting it into (9), we find

$$\left(c_t^e\right)^{-\frac{1}{\psi}} = \left(1 + \lambda_t\right) \mu_t^w,$$

where λ_t is the variable Shi (2015) calls the liquidity services defined as

$$\lambda_t = \frac{p_{n,t} \vartheta_t - 1}{1 - \theta p_{n,t} \vartheta_t}.$$

Our assumption $1 < p_{n,t} \vartheta_t < 1/\theta$ implies that the liquidity services are always positive and therefore entrepreneur's marginal utility of consumption is greater than worker's in the equilibrium. This is so because freeing up a unit of resource in the entrepreneur's budget constraint is more valuable to the household than freeing up a unit of resource in the worker's budget constraint.

Prices of equity and capital are determined by

$$p_{n,t} = \mathbb{E}_t \left[\beta \left(\frac{\mu_{t+1}^w}{\mu_t^w}\right) \left(\left(1 - \tau_p\right) \Pi_{t+1} + p_{n,t+1} \left(1 - \delta_n\right) + \sigma_e \lambda_{t+1} \left[\left(1 - \tau_p\right) \Pi_{t+1} + \phi_{t+1} p_{n,t+1} \left(1 - \delta_n\right)\right]\right)\right], \tag{10}$$

and

$$p_{k,t} = \mathbb{E}_t \left[\beta \left(\frac{\mu_{t+1}^w}{\mu_t^w}\right) \left(\begin{array}{c} \left(1 - \tau_p\right) u_{t+1} R_{t+1} + p_{k,t+1} \left(1 - \delta\left(u_{t+1}\right)\right) \\ + \sigma_e \lambda_{t+1} \left[\left(1 - \tau_p\right) u_{t+1} R_{t+1} + \phi_{t+1} p_{k,t+1} \left(1 - \delta\left(u_{t+1}\right)\right)\right] \end{array}\right)\right], \tag{11}$$

respectively. (10) says that the price of equity reflects not only the present discounted value of future cash flow but also the present discounted value of future liquidity services. The liquidity services are counted in because a product provides liquidity to entrepreneurs through dividends and its (partial) resalability in the asset market. An analogous intuition applies to (11). Finally, the optimality condition for capacity utilization rate is given by

$$\left(1 - \tau_p\right) R_t - p_{k,t} \delta'\left(u_t\right) + \sigma_e \lambda_t \left[\left(1 - \tau_p\right) R_t - \phi_t p_{k,t} \delta'\left(u_t\right)\right] = 0$$

The head of the household cares about not only the usual trade-off between revenue (the first term) and depreciation (the second term) but also how much liquidity she can provide to entrepreneurs with capital (the third term).

2.2 Final goods sector

There is a representative firm that uses capital service KS_t, labor L_t, and a composite of intermediate goods G_t to produce the final (consumption) good according to the production technology

$$Y_t = \left((KS_t)^{\alpha} (A_t L_t)^{1-\alpha}\right)^{1-\xi} G_t^{\xi},$$

where G_t is defined as

$$G_t = \left[\int_0^{N_t} X_{i,t}^{\frac{1}{\nu}} di\right]^{\nu}.$$

$X_{i,t}$ is intermediate good $i \in [0, N_t]$, α is the capital share, ξ is the intermediate goods share, and ν is the parameter affecting the elasticity of substitution between intermediate goods. A_t is an exogenous technology shock. The firm maximizes profits defined as

$$Y_t - R_t (KS_t) - W_t L_t - \int_0^{N_t} P_{i,t} X_{i,t} di,$$

where $P_{i,t}$ is the price per unit of intermediate good i, which the final goods firm takes as given. Solving the cost minimization problem of purchasing intermediate goods leads to the downward-sloping demand function:

$$X_{i,t} = \left(\frac{P_{i,t}}{P_{G,t}}\right)^{\frac{\nu}{1-\nu}} G_t,$$

where $P_{G,t}$ is the price index defined as $P_{G,t} = \left[\int_0^{N_t} P_{i,t}^{\frac{1}{1-\nu}} di\right]^{1-\nu}$. We omit the first-order optimality conditions because they are standard.

2.3 Intermediate goods sector

The marginal cost of producing an intermediate good is unity as we assume roundabout technology. The producer chooses its price $P_{i,t}$ to maximize the profits defined as

$$\Pi_{i,t} \equiv \max_{P_{i,t}} (P_{i,t} - 1) \left(\frac{P_{i,t}}{P_{G,t}}\right)^{\frac{\nu}{1-\nu}} G_t.$$

Solving this problem leads to the optimal markup pricing, $P_{i,t} = \nu$. Since prices are symmetric, so are production levels and profits. Let X_t denote the symmetric production level, i.e., $X_t = X_{i,t}$ for all $i \in [0, N_t]$, and let Π_t denote the symmetric profits, i.e., $\Pi_t = \Pi_{i,t}$ for all $i \in [0, N_t]$. Profits are paid out to shareholders as dividends.

2.4 Product development technology

The technology coefficient of product development is defined as

$$\vartheta_t = \frac{\zeta N_t}{(\sigma_e s_t)^{1-\eta} (N_t)^{\eta}},$$

where $\eta \in [0, 1]$ is the elasticity of new intermediate goods with respect to R&D, and ζ is a scale parameter. The product innovation efficiency improves with N_t. This is knowledge spillover à la Romer (1990), with the stock of available varieties in the economy interpreted as the stock of knowledge in the society. The product innovation efficiency decreases with $\sigma_e s_t$. This is a congestion externality effect capturing decreasing returns to scale in the innovation sector. N_t's transition rule is given by

$$N_{t+1} = (1 - \delta_n) N_t + \vartheta_t (\sigma_e s_t).$$

Notice that because $\vartheta_t (\sigma_e s_t) = \zeta (\sigma_e s_t)^{\eta} (N_t)^{1-\eta}$, the right-hand side is homogeneous of degree one in N_t and s_t. The growth rate of N_t therefore depends on the ratio of these two variables, and as a consequence, growth does not slow down as long as this ratio is stationary. This is an important insight in the endogenous growth literature. An equally important implication for our study is that the model can link the trend and the cycle. Specifically, since the model's growth mechanism relies on a virtuous circle between R&D and knowledge spillover, a recession might leave permanent effects on the trend economy if it causes a severe disruption in R&D.

2.5 Government

We assume that government consumption Gov_t is given by $Gov_t/N_t = g_t$, where g_t is an exogenous random variable we call the government consumption shock. Furthermore, the government keeps its budget balanced:

$$Gov_t + \tau_{tr,t} = \tau_p (\Pi_t N_t + u_t R_t K_t) + \tau_l W_t \sigma_w l_t.$$

Note that an increase in government consumption must be financed mainly through a reduction in transfer payments ($\tau_{tr,t}$) because tax rates (τ_p and τ_l) are constant. In this sense, government consumption shocks act as income shocks in disguise. Alternatively, we could have a stochastic transfer payment and assume that the government adjusts Gov_t to keep its budget balanced, without affecting much our findings. We model income shocks to entrepreneurs with the current formulation for three reasons. First, this approach has the advantage that the government budget constraint imposes discipline in the way these shocks move. Second, this approach is arguably more structural that assuming an ad hoc income shock hitting directly entrepreneurs' balance sheet. Finally, government consumption shocks are conventional in the literature.

2.6 Equilibrium

The competitive equilibrium is defined in a standard way. Market clearing conditions for production factors are $KS_t = u_t K_t$ and $L_t = \sigma_w l_t$. Goods market clearing condition is

$$Y_t = \sigma_e c_t^e + \sigma_w c_t^w + \sigma_w \frac{i_t}{\chi_t} + \sigma_e s_t + Gov_t + N_t X_t.$$

Asset market clearing conditions are $N_t = n_t$ and $K_t = k_t$ at the beginning of period t, and $N_{t+1} = \sigma_e n_{t+1}^e + \sigma_w n_{t+1}^w$ and $(1 - \delta(u_t)) K_t = \sigma_e k_{t+1}^e + \sigma_w k_{t+1}^w$ at the end of period t.

Following Kung and Schmid (2015), we make the parameter restriction $\alpha + \frac{\nu\xi - \xi}{1-\xi} = 1$. An advantage of this assumption is that we can rewrite the final goods production as

$$Y_t = (KS_t)^{\alpha} (Z_t L_t)^{1-\alpha},$$

where Z_t is given by $Z_t = \left(\bar{A}\right)(A_t N_t)$, and $\bar{A} \equiv \left(\frac{\xi}{\nu}\right)^{\frac{\xi}{(1-\xi)(1-\alpha)}} > 0$ is a constant. The dependence of Z_t on N_t is a well-known variety effect; the expansion of product varieties allows more efficient use of labor and capital in final-goods production.

Turning to the national income accounting, the goods market clearing condition implies that

$$\mathcal{Y}_t = \sigma_e c_t^e + \sigma_w c_t^w + \sigma_w \frac{i_t}{\chi_t} + \sigma_e s_t + Gov_t,$$

where $\mathcal{Y}_t$ is the value added output defined as $\mathcal{Y}_t \equiv Y_t - N_t X_t$, which is related to the gross output as $\mathcal{Y}_t = \left(1 - \frac{\xi}{\nu}\right) Y_t$. The value added output is the sum of consumption, investment, R&D, and government consumption. Another approach to the value added output is from income. The Cobb-Douglas production function and the accounting identity that the sum of costs and profits has to be equal to revenues imply

$$\mathcal{Y}_t = R_t (u_t K_t) + W_t (\sigma_w l_t) + N_t \Pi_t.$$

The value added output is the sum of compensations for capital and labor, and profits. We define the aggregate stock market value as

$$Stock_t = p_{n,t} N_{t+1} + p_{k,t} (1 - \delta(u_t)) K_t.$$

We do not include investment to physical capital in the definition of $Stock_t$ because we assume in the model that investment takes place at the very end of a period at which the asset markets are already closed. We define total factor productivity (TFP) as

$$TFP_t = \frac{\mathcal{Y}_t}{(K_t)^{\alpha} (L_t)^{1-\alpha}}.$$

This is standard, and more importantly, is consistent with Fernald (2014). In our model economy,

growth in TFP is conveniently rewritten as the weighted sum of growth in utilization, growth in the technology shock, and growth in the varieties;

$$\log\left(\frac{TFP_t}{TFP_{t-1}}\right) = \alpha \log\left(\frac{u_t}{u_{t-1}}\right) + (1-\alpha)\log\left(\frac{A_t}{A_{t-1}}\right) + (1-\alpha)\log\left(\frac{N_t}{N_{t-1}}\right).$$

Roughly speaking, both utilization and technology shocks are responsible for high-frequency movements in TFP because they are stationary in levels, whereas the product variety is responsible for secular movements because it is stationary in growth rates. The appendix provides further discussion on TFP.

2.7 Structural Shocks

There are five structural shocks, ϕ_t, φ_t, A_t, g_t, and χ_t, in our model, each of them is modeled as an AR(1) process with *iid* innovations. Hence, the generic specification of our shocks is

$$\log\frac{\varsigma_t}{\varsigma} = \rho_\varsigma \log\frac{\varsigma_{t-1}}{\varsigma} + \sigma_\varsigma \varepsilon_\varsigma,$$

where ρ_ς and σ_ς are the persistence and standard deviation of the stochastic process. The innovation ε_ς is assumed to follow a normal standard distribution.

3 Estimation

We take a stringent approach regarding the calibration/estimation of our model. First, we tie our hands by setting most of the structural parameters to either values used elsewhere or to match some incontrovertible ratios in the data. Then we estimate the rest of the parameters. This way, we put the structural shocks at the forefront of our analysis.

The following parameters are fixed in the estimation. The discount factor β is set to 0.99, which is standard in the literature. The intertemporal elasticity of substitution ψ is set to 1.85, consistent with the value used in Kung and Schmid (2015) and within the credible set estimated by Schorfheide, Song, and Yaron (2014). The research elasticity η is set to 0.9, which is roughly consistent with the value used in Comin and Gertler (2006) and Kung and Schmid (2015). The exit rate δ_n is set to 0.03, in line with the value used in Bilbiie, Ghironi, and Melitz (2012). The capital depreciation rate in the steady state δ_k is set to 0.03. Following Del Negro, Eggertsson, Ferrero, and Kiyotaki (2011) and Shi (2015), we set the resalability of new equities θ to 0.15. Taxes on capital income τ_p and labor income τ_l are set to 0.42 and 0.40, respectively, both of which are taken from Greenwood, Hercowitz, and Krusell (1997). The steady state utilization u is set to 1.0.

The following parameters are calibrated either using model properties or targeting empirical moments. The marginal capital depreciation rate in the steady state, δ', is pinned down by the equilibrium condition. The elasticity of labor in the home production, ω, is difficult to calibrate;

we take a parsimonious approach and set it equal to the elasticity of labor in the market sector, i.e., $\omega = 1 - \alpha$. The steady state government consumption shock, g, is set so that government consumption share in the value-added output in the steady state is 0.2. The scale parameter in the product innovation function, ζ, the labor-augmenting technology shock in steady state, A, and the preference shock in steady state, φ, are set so that (i) the model's steady state growth rate is matched to the average growth rate of the economy in the data (2.7% per year), (ii) the gross output in the steady state of the detrended system is normalized to be one, and (iii) the steady state labor supply per worker is matched to the empirical target $l = 1/3$.

The capital elasticity, α, the gross markup of an intermediate good, ν, and the entrepreneur's share in the population, σ_e, are calibrated to match the following targets in the steady state: (i) the labor share in the value-added output (57%), (ii) the investment share in the value-added output (11%), and (iii) the R&D share in the value-added output (6%). The labor share is the one calculated by Rios-Rull and Santaeulalia-Llopis (2009) defining it as the ratio of compensation of employee over gross national product. Investment is narrowly defined as the business investment in structure and equipment, because tangible capital in the business sector is the closest concept to physical capital in our model. Finally, we take a broad definition of R&D, because, we believe that in reality, products are able to distinguish themselves from other products not only by the formal patent system but also by informal protections surrounding trade secrets, brand images, business models, and so on. Such a consideration leads us to use the data reported in Nakamura (2003), who argues that a more accurate portrayal of intangible capital in the economy is given by twice the measure of software plus twice the value of R&D (both taken from NIPA) plus a measure of advertisement spending (compiled by the advertising agency McCann and Erickson). The empirical targets do not give enough restrictions to pin down all the calibrated parameters until we specify the value of the liquidity shock in the steady state, ϕ. We will estimate ϕ for the reason we discuss below, but throughout the estimation, we keep adjusting the calibrated parameters so that the parametrized model matches the empirical targets.

In previous work (Guerron-Quintana and Jinnai (2014)), we found that the propagation mechanism of our model is dictated in part by the elasticity of the depreciation rate with respect to capital utilization in steady state, δ''/δ', the liquidity shock in the steady state, ϕ, and the investment adjustment costs, $\bar{\Lambda}$. Therefore we estimate these parameters to let the data inform us about what are reasonable values. Since the structural shocks are at the crux of our empirical investigation, we also estimate the persistence and volatility of these stochastic processes. To this end, we use quarterly data on output, consumption, investment, labor, the valuation of the stock market, Fernald's measure of total factor productivity, and a measure of financial conditions discussed below. Output and investment are adjusted in order to make them consistent with our model; namely, R&D is excluded from investment, and output is adjusted so that it reflects the broader measure

of R&D.[19] The sample covers 1970.Q1 - 2011.Q4.[20] Except for labor and the financial measure, all variables are expressed in growth rates. Note that we are estimating our model including the Great Recession sample. By doing so, we share Stock and Watson (2012)'s view that the crisis resulted from the same set of shocks that buffeted the economy in the past. This imposes further discipline in our decomposition.

Our measure of financial conditions is based on the first principal component of the liquidity/financial risk shocks considered by Stock and Watson (2012).[21] We use it as an empirical counterpart of the liquidity shock in our model for the following reasons. First, although it is not a direct measure of asset resalability, it does measure the general stance of financial markets. In this sense, to the extent that asset markets in our model play the role of the actual financial markets, the empirical measure and the liquidity shock are similar in essence. Second, Stock and Watson's data are arguably the best available source of exogenous shocks originating in the financial sector; the authors use them as instruments for this reason. Because exogeneity is crucial to identify our liquidity shock as well, their data are suitable for our study too. We directly link the liquidity shock to Stock and Watson's financial shock. But here, we face the delicate choice of how to align the scales of these objects. One obvious choice is that one percentage point change in the model corresponds to one percentage point change in the data. But given the abstract relation between the two, it is far from obvious that this is the best option. We therefore take an alternative route based on Bayes factor comparisons (Geweke (2005)), finding that the map preferred by the data is the one in which a percentage point change in the data corresponds to ϕ percentage points in the model. That is, if sw_t is liquidity in the data, our measurement equation is $\widehat{sw}_t = \phi\widehat{\phi}_t$, where the variables are expressed in percentage deviations from their steady states. In the appendix, we provide further details on the data.

Adding two measurement errors to the model with five structural shocks enables us to use seven series in the estimation. The first measurement error (with volatility σ_m) enters into the observable equation of the growth rate of the stock market value.[22] It is introduced to cope with a well known handicap of dynamic stochastic general equilibrium models; i.e., they have difficulties matching the volatile profile of the stock market (Cochrane (2008)). Both Bernanke and Gertler (1999) and Schorfheide, Song, and Yaron (2014) rely on similar measurement errors.

Second, we introduce a measurement error (with volatility σ_t) to the observation equation associated to the growth rate of TFP. This measurement error is intended to account for the conceptual gap between the model and the data. Namely, Fernald takes heterogeneity of both capital goods

[19] The annual series was interpolated using the algorithm of Fernandez (1981) with NIPA's R&D quarterly series as the reference entry.

[20] We are limited by the availability of the financial data from Stock and Watson, which ends in 2011.

[21] Guerron-Quintana and Jinnai (2014) use margins for S&P 500 futures as an alternative measure of liquidity, which moved remarkably similar to Stock and Watson's data.

[22] Let $g_{s,t}$ denote the growth rate of the stock market in the model. The measurement equation for estimation is $g^o_{s,t} = g_{s,t} + m_{s,t}$, where $g^o_{s,t}$ is the stock market value growth in the data. The measurement equation for TFP is analogous.

and workers, as well as labor quality, into account to purify his technology measure. But their variations can be a source of measurement error in the estimation, as our model abstracts from them. Furthermore, his measure corresponds to the business sector while we consider the overall economy. The measurement error is also intended to account for measurement error in the literal sense. That is, despite an admirable effort of Fernald to measure TFP, with which we learn about the evolution of the technology with unprecedented quality, we believe that it is still not free from error, simply because technology is inherently noisy (Hall (2014)). We assume that both measurement errors are *iid* shocks without persistence.

The model is estimated using Bayesian methods. For the structural parameters, we select the following priors: a Gamma distribution with mean 0.1 and standard deviation 0.025 for δ''/δ', which is roughly consistent with the calibrations of Jaimovich and Rebelo (2009) and King and Rebelo (1999); a Gamma distribution with mean 0.15 and standard deviation 0.025 for ϕ, in line with the calibrations of Del Negro, Eggertsson, Ferrero, and Kiyotaki (2011) and Shi (2015); the adjustment cost of investment parameter ($\bar{\Lambda}$) has a Gamma prior with mean 5, which is close to the estimated value in Christiano, Eichenbaum, and Trabandt (2015), and standard deviation 2. Regarding the stochastic processes, we select two types of priors: for the one related to persistence (ρ), we use a Beta distribution with mean 0.5 and standard deviation 0.2; the prior for the standard deviation of the structural shocks (σ) is an Inverse Gamma with parameters 6 and 1. Both priors are fairly standard choices in the literature. To limit the impact of the measurement errors in our estimation, we use uniform priors $[0, \widetilde{\sigma}]$, where the upper limit is set to 20% of the volatility of the growth rate of TFP and 35% of the volatility of the growth rate of the stock market value (Schmitt-Grohe and Uribe (2012)). We use a random-walk Metropolis Hasting simulator to characterize the posterior distributions of the parameters of interest. The acceptance rate of the simulator is set to around 30% (Robert and Casella (2004)). After an extensive search for the mode and a burn-in period, the posteriors' statistics were computed with $600,000$ draws. We ensure convergence of the chains to their ergodic distributions by checking the raw chains, cumulative means and cumulative sums plots (Robert and Casella (2004)). See the appendix for additional information and figures.

The right column of table 1 reports the median and the 0.05 and 0.95 percentiles of the posterior distributions. A few points merit some discussion. First, the curvature of the investment adjustment cost ($\bar{\Lambda}$) is small compared to values in the literature (Christiano, Eichenbaum, and Evans (2005)). Second, our estimates show that there is some degree of liquidity in the data (given by the strictly positive value of ϕ), but it is smaller than the values used in previous work (Del Negro, Eggertsson, Ferrero, and Kiyotaki (2011) and Shi (2015)). Third, the elasticity of $\delta'(u)$ evaluated at the steady state is very close to the parameter values used by Comin and Gertler (2006) and Jaimovich and Rebelo (2009). Finally, one can see that the shocks displays different degrees of persistence and volatility.

The left column of table 1 reports the calibrated parameters when ϕ is at its posterior median. The capital elasticity is smaller than the one in the standard neoclassical growth model, but $\alpha = 0.2$

Table 1: Parameter Values

Fixed/Calibrated			Estimated		
Parameter	Value	Reference/Target	Parameter	Median	90% Interval
β	0.99	Standard	ρ_A	0.901	[0.872,0.937]
ψ	1.85	Kung and Schmid (2015)	ρ_ϕ	0.996	[0.993,0.998]
η	0.9	Comin and Gertler (2006)	ρ_g	0.987	[0.984,0.989]
δ_n	0.03	Bilbiie et. al. (2012)	ρ_φ	0.879	[0.845,0.907]
δ_k	0.03	Standard	ρ_χ	0.642	[0.574,0.704]
θ	0.15	Del Negro et al. (2011)	σ_A	0.015	[0.013,0.016]
τ_p	0.40	Greenwood et al. (1997)	σ_ϕ	0.033	[0.029,0.039]
τ_l	0.42	Greenwood et al. (1997)	σ_g	0.046	[0.041,0.051]
u	1.0	Normalization	σ_φ	0.012	[0.011,0.014]
δ'	0.03	Model's Implication	σ_χ	0.023	[0.019,0.027]
ω	0.8	$\omega = 1 - \alpha$	σ_m	0.030	[0.029,0.030]
g	0.16	$Gov_t/GDP_t = 0.2$	σ_t	0.007	[0.006,0.007]
ζ	0.58	Average Growth Rate	δ''/δ'	0.268	[0.214,0.330]
A	2.46	$Y_t/N_t = 1$	ϕ	0.121	[0.105,0.138]
φ	0.36	$l_t = 1/3$	$\bar{\Lambda}$	0.590	[0.502,0.694]
α	0.20	Capital Share			
ν	2.00	Investment Share			
σ_e	0.02	R&D Share			

is consistent with the value chosen by Schmitt-Grohe and Uribe (2012) or the value estimated by Christiano, Eichenbaum, and Trabandt (2015). The gross markup is slightly larger than the value used by Comin and Gertler (2006) and Kung and Schmid (2015), but the empirical evidence on the markup for specialized intermediate goods is unfortunately very weak. The share of entrepreneurs in the population is smaller than the one chosen by Del Negro, Eggertsson, Ferrero, and Kiyotaki (2011) and Shi (2015), but we think that this is reasonable because entrepreneurs in our model economy conduct a more specialized task (innovation) than entrepreneurs in the aforementioned studies (investment to physical capital).

4 Results

4.1 Basic Properties

This section discusses the model's basic properties. We start with impulse response functions as they provide insight into the inner workings of our model. The first row of Figure 3 shows that a positive liquidity shock (loosening the liquidity condition) increases R&D; a higher R&D improves productivity; and through the endogenous growth mechanism, it will lead the economy to settle in a higher trend (we plot deviations of the variables from their original trends). The persistent effects of a liquidity shock are important to reconcile the apparent transitory nature of the shocks during

the Great Recession with a seemingly permanent downturn shift in the economy's trend following the crisis. We elaborate on this point momentarily.

A favorable liquidity shock also increases output, investment, consumption, hours worked, and the stock market value. These results are interesting because liquidity shocks are often criticized for their unorthodox predictions. Indeed, in a model with liquidity shocks exemplified by Kiyotaki and Moore (2012), a loosening of the liquidity condition tends to decrease consumption as it is substituted with investment. Furthermore, a flood of (tradable) assets in the market decreases the price of each asset, triggering a bust in the stock market.

To the comovement problem between investment and consumption, the literature knows at least two fixes; i.e., Ajello (2014) demonstrates that nominal wage rigidities are a mechanism to solve the problem, and Shi (2015) shows that consumption can increase if it is costly to increase investment above its steady state level. The current paper proposes another solution based on the insight of Jaimovich and Rebelo (2009).[23] The mechanism works as follows. Because a positive liquidity shock raises the economy's trend, the household, becoming wealthier, has a strong incentive to increase consumption. In the absence of investment adjustment costs, the household would substitute consumption with investment, but in our model, the presence of adjustment costs penalizes abrupt movements in investment. Moreover, the household even increases investment, since capital should be accumulated as the economy transitions to a new and higher trend, and for that, investment growth should be gradually increased.

With incentives to increase both consumption and investment, the household ends up raising the capacity utilization rate, which raises the marginal product of labor. If labor supply is constant, the improved labor productivity (an outward shift in the labor demand schedule) will attract more labor to the market with a higher wage. However, this substitution effect is usually dominated by the wealth effects on labor supply (an inward shift in the labor supply schedule) if the household's utility is the one proposed by King, Plosser, and Rebelo (1988).[24] This wealth effect on labor supply is absent in our model, because the utility function is in the class proposed by Greenwood, Hercowitz, and Huffman (1988). As a result, the labor market sees a high-wage, high-employment equilibrium.[25]

The counterfactual response of the stock market is perhaps a deeper problem because it is robust

[23] Jaimovich and Rebelo (2009) offers a solution to a comovement problem in the news shock literature; namely, a standard neo-classical growth model predicts that an arrival of a good news taking the form of an exogenous rise in future productivity increases consumption but decreases hours worked by the wealth effect, leading to declines in output and investment. They introduce three elements to an otherwise standard neo-classical growth model: variable capacity utilization rate, investment adjustment costs, and a utility function with weak short-run wealth effect on labor supply. Note that our model has all of them.

[24] This is a robust finding in the news shock literature and a problem recognized earlier by Barro and King (1984) and Cochrane (1994).

[25] In principle, the above mechanisms can be strong enough to generate comovement among output, consumption, investment, and labor. Not surprisingly, however, the exact prediction depends on parameters. In our model, the endogenous trend term in the utility function induces more substitution of market hours with non-market hours, making the prediction relatively robust to parameter specifications.

to a wide range of specifications (Shi (2015)).[26] Shi postulates that it is necessary for the liquidity shock to be accompanied or caused by other shocks in order to generate a positive response of the stock market to favorable liquidity. In fact, negative liquidity shocks are accompanied by a government liquidity injection in Del Negro, Eggertsson, Ferrero, and Kiyotaki (2011) whereas a shock to the collateral constraint is correlated with future TFP in Jermann and Quadrini (2012). The later paper is particularly interesting, because its result reveals the importance of the inter-dependence between asset liquidity and productivity. Our study shares a similar insight, but we incorporate it by explaining the inter-dependence rather than assuming it.[27]

In our model, the stock market value rises because the intangible capital value $p_{n,t}N_{t+1}$ does. To understand this response, note that a positive liquidity shock raises output, which in turn raises aggregate profits (recall that profits are proportional to output in our setup). With a constant discount factor, increases in future cash flows would raise the present discounted value of the asset, but this logic is incomplete in our model because the stochastic discount factor is endogenous. Now remember that we assume that the intertemporal elasticity of substitution is greater than one, implying that the stochastic discount factor does not react much to a change in the consumption-growth profile or other factors. Therefore, the intuitive argument made under the false assumption of constant discount factor survives in the general setup. This insight is essentially the same as the one known in the long-run risk literature in finance (Bansal and Yaron (2004)). To clarify the generality of the mechanism, we construct a simple endogenous growth model with learning-by-doing in the appendix. Although auxiliary elements are stripped out, a positive liquidity shock still raises the stock market value. This result suggests that both the endogenous growth mechanism and the intertemporal elasticity of substitution are the only crucial elements.

The second row of Figure 3 shows the dynamic paths following a government consumption shock. Before discussing them, recall that in standard RBC models, this shock is often expansionary because of the following mechanism. A rise in government consumption is financed by an increase in tax revenues and/or a reduction in transfer payments. In either case, the labor supply schedule shifts outward because of the negative wealth effect, leading to a higher production. This mechanism, however, is absent in our model because of the utility function we adopted. Instead, the following mechanism is in effect in our model. A decline in transfer payments reduces entrepreneurs' income as well as workers' income. If financial markets were functioning well, the problem would be small because they can agree upon a mutually beneficial sharing of the burden (a reduction in

[26] Shi (2015) focuses on the equity price (the price of a unit of capital), but not on the aggregate stock market value (the equity price times the capital stock). The distinction between the two measures is of little consequence in his model, because the capital stock is a state variable incapable of making jumps. In contrast, the distinction is important in our model, because there are two kinds of assets: capital and products. We believe that in this situation, the aggregate stock market value is a more suitable measure to discuss the asset price implication of liquidity shocks than either the price of a unit of capital or the price of a product, because its empirical counterpart is arguably clearer.

[27] Ajello (2014) models the inter-dependence elegantly. In his model, an increase in the financial intermediation cost influences the quality distribution of investments, and as such, it acts as a negative shock to productivity as well as to liquidity. His model is able to generate positive comovement of asset prices over the business cycle.

transfers). But the financial frictions limit the economy's capacity to do so, and hence, a reduction in entrepreneurs' income suppresses R&D, and the economy settles down in a trend below the pre-shock one. The pessimistic view toward the long-run equilibrium causes a slowdown in economic activities by setting off an amplification mechanism akin to the one discussed above.

Interestingly, our findings about the effects of government purchases on the economy might help understand some puzzling results in the literature. Indeed, the empirical evidence on the effects of government purchases is contentious, to say the least. It has been equally argued that these purchases can cause a contraction or expansion in the economy. For example, Leeper, Traum, and Walker (2011) report that government multipliers for output in the literature range from -0.26 to more than 1 on impact. In the long run, the multipliers fluctuate between -1.0 and 1.4. Mountford and Uhlig (2009) consider a sign approach in a VAR framework to identify the effects of government spending changes in the United States for the period 1955-2000. One of the identified cases requires that the government budget be balanced, which is the same exercise as in our model. Under this restriction, the authors report that on impact GDP barely moves following an expansionary government spending shock. Thereafter, the shock causes an overall contraction with output, consumption, investment, and real wages declining. Importantly, the negative relation between the shock and economic activity is found to be significant both in the short and long run. Our model provides a compelling and parsimonious explanation to this negative correlation.

The final comment on government consumption shocks is about its interpretation. As we discussed before, government consumption shocks are income shocks in disguise, and as such, they might pick up disturbances to the households' income due to factors that are not explicitly included in the model. According to this interpretation, the result says that a recession follows a negative income shock because innovative activities are not funded due to the lack of internal resources entrepreneurs could otherwise rely on. We will get back to this possibility in the next section.

In our framework, shock amplification is clearly important to generate reasonable comovement in the short-run. We elaborate on this issue later, but a few comments are worth mentioning now. First, it is the data that prefer strong amplification; remember that we estimate some crucial parameters influencing the degree of shock amplification including the elasticity of $\delta'(u)$ in the steady state and the persistence of the structural shocks. Second, the mechanisms in the short-run and the long-run reinforce each other. The above discussion dealt with only one side; i.e., the economy experiences a short-run boom given that the economy transitions to a new (higher) trend. Conversely, the short-run boom creates a favorable condition for innovative activities by loosening entrepreneurs' financial position, leading the economy to an even higher trend. On the latter issue, it is Comin and Gertler (2006) who first point out that business cycle disturbances at the high frequency may produce medium-frequency oscillations.

We briefly comment on the remaining impulse responses, summarized in Figure 4, as they are fairly standard and intuitive. A positive technology shock causes an immediate economic boom, being consistent with a large literature emphasizing its role in the business cycle (King, Plosser,

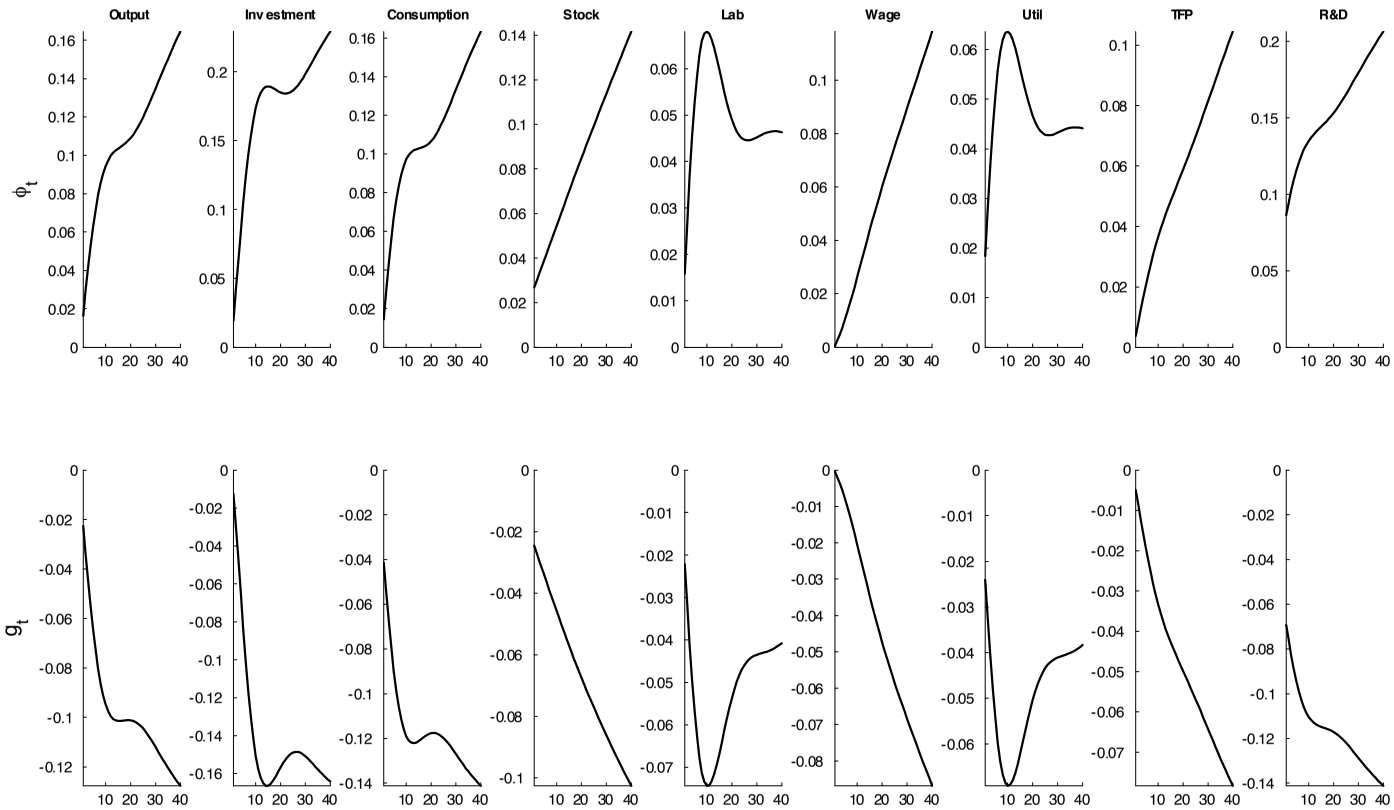

Figure 3: Impulse Responses to Liquidity Shock and Government Consumption Shock

Table 2: Variance Decomposition

	Δy	Δc	Δi	l	sw	$\Delta stmk$	Δtfp
ϕ	0.27	0.17	0.22	0.64	1.00	0.53	0.59
A	0.24	0.26	0.23	0.03	0.00	0.01	0.19
g	0.15	0.19	0.13	0.28	0.00	0.21	0.15
φ	0.26	0.31	0.09	0.02	0.00	0.01	0.02
χ	0.08	0.07	0.32	0.03	0.00	0.02	0.02
m	0.00	0.00	0.00	0.00	0.00	0.22	0.00
t	0.00	0.00	0.00	0.00	0.00	0.00	0.03

and Rebelo (1988)). A preference shock (increasing the productivity of home production) cause a recession characterized by simultaneous decreases in output, investment, consumption, hours worked, and the stock market value, as the household substitutes non-market hours with market hours. An M.E.I. shock (increasing the efficiency in converting consumption goods to investment goods) increases investment on impact. The common thread of these three shocks is the transitory nature; it is clear that the economy largely reverts, or at least starts to revert, back to the original trend within 5 years after the shocks.

With the conditional predictions of the structural shocks in hand, it is of interest to know their contributions to the business cycle. We report in Table 2 the variance decomposition for different shocks (rows) and observables (columns). An insight from this exercise is that the liquidity shock (ϕ) is an important driver of the business cycle; it explains for example about a quarter of output growth variation (Δy) over the business cycle.[28] Our paper therefore joins a recent and growing literature emphasizing the importance of financial frictions. For example, Ajello (2014) and Christiano, Motto, and Rostagno (2014) estimate variants of DSGE models with financial frictions, finding that financial shocks are the main driving force of the business cycle. We also find that the technology shock (A) and the government consumption shock (g) are as important as the liquidity shock. Interestingly, the importance of government consumption for business cycles in our model is reminiscent of the results in Christiano and Eichenbaum (1992) and Smets and Wouters (2007) although the propagation mechanisms are different.

To conclude this section, we briefly comment on the role of the remaining shocks. The preference shock (φ) is important to explain variations in output and consumption (Δc) while the M.E.I. shock (χ) is important to explain the volatility of investment (Δi). Measurement errors to both the stock market value (m) and TFP (t) pick up some volatility in the data ($\Delta stmk$ and Δtfp).

[28] That our liquidity shock explains all of the variation in Stock and Watson's measure (sw) is by construction.

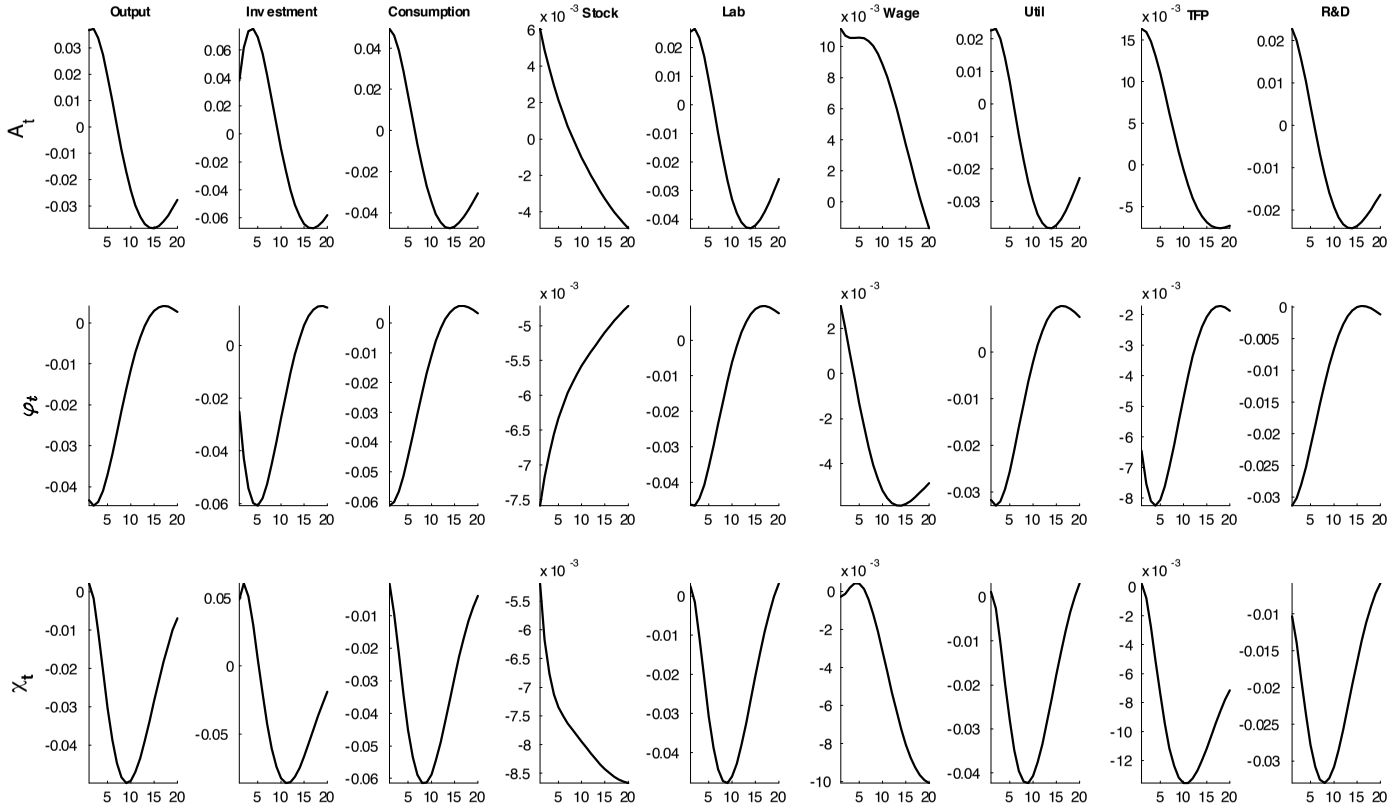

Figure 4: Rest of Impulse Responses in Baseline Model

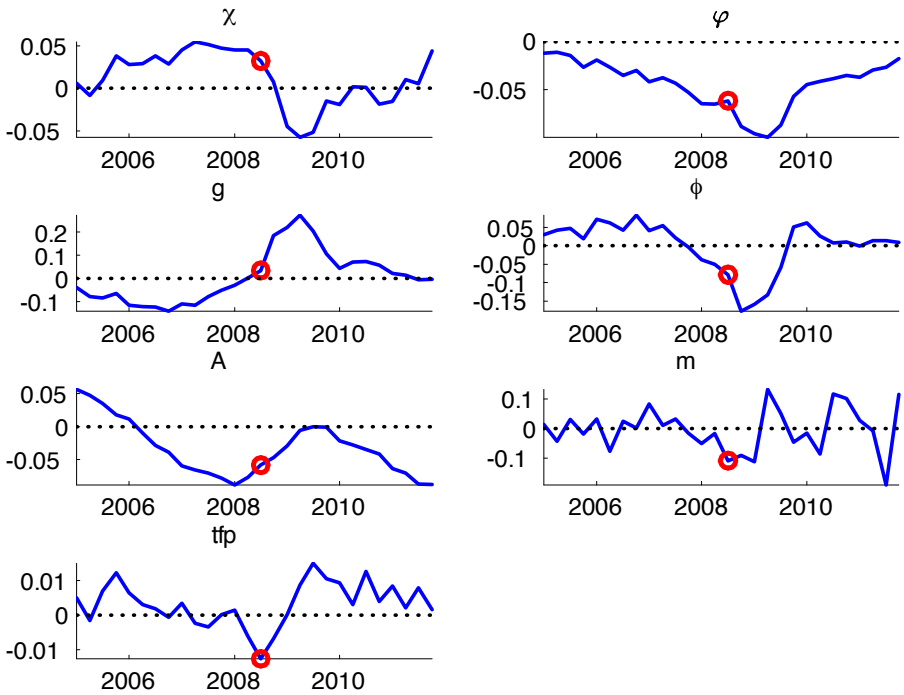

Figure 5: Smoothed Shocks during Great Recession

4.2 What drove the Great Recession?

Equipped with our estimated model, we now provide an account of the 2008/2009 crisis and the subsequent tepid recovery. Figure 5 shows the smoothed paths for the stochastic processes (ς_t) around the Great Recession (the red dot indicates 2008.Q3). Clearly, the economy experienced strong headwinds because investment goods (χ) became more expensive, liquidity (ϕ) deteriorated, and government consumption (g) increased, resulting in a reduction of transfers.[29] Our estimation, however, uncovers that the economy embraced some favorable shocks as well. That is, the preference shock (φ) induced households to substitute non-market hours with market hours, and the technology shock (A) improved the efficiency of goods production. We suspect that positive shocks to A pick up the improvement in labor quality reported by Fernald (2014) perhaps caused by disproportionate layoffs of low-skilled workers.

Figure 6 helps us to understand how each shock contributed to the Great Recession. We compute the path for output growth if only one shock is the driver of the economy at a time, and stack them in bar charts.[30] It is clear that both the liquidity shock and the government consumption shock

[29] Interestingly, the actual total government expenditure looks similar to the estimated path of g; it rises sharply in 2008 and then drops around the start of 2011. See Christiano, Eichenbaum, and Trabandt (2015).

[30] Mechanically, we shut down all shocks but one and simulate the economy starting in 1971. We use the smoothed

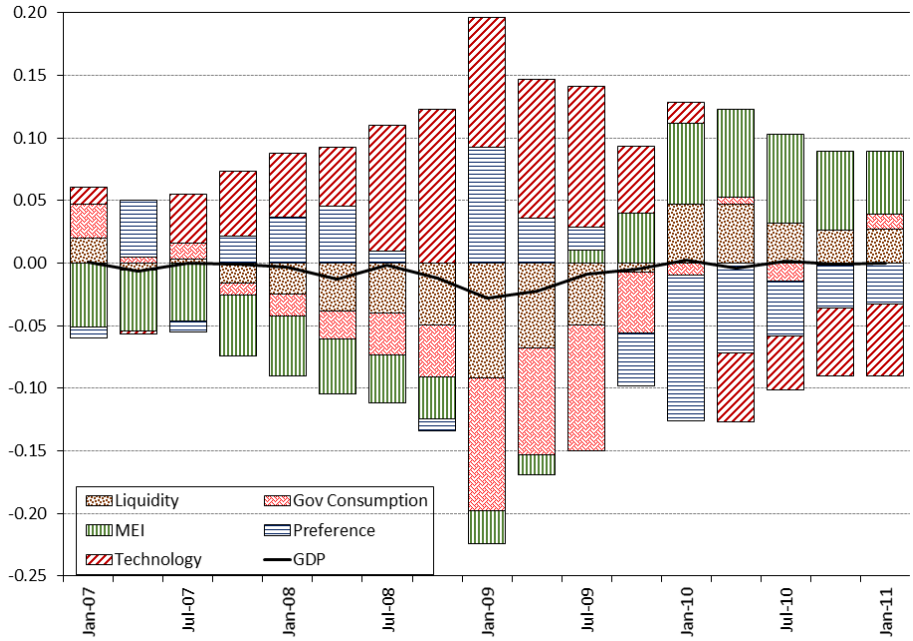

Figure 6: Shock decomposition during Great Recession.

dragged the economy into the recession despite counterbalances provided by the preference and technology disturbances. The figure also highlights the importance of liquidity during the recovery phase; a strong headwind between 2008 and 2009, the liquidity shock turns into a tailwind in 2010. In contrast, the government consumption shock does not share the same dynamics; although it becomes nearly neutral to GDP growth in 2010, it does not become a favorable force. Our narrative behind the government consumption shock is reminiscent of the housing net worth channel of Mian and Sufi (2014). Remember that in our model, an increase in the government consumption decreases the households' exogenous income. We conjecture that a sharp reduction in the housing net worth, or at least part of it that is due to exogenous factors to our model such as mortgage fraud (Mian and Sufi (2015)), may be captured as a rise in the government consumption in the estimation. If so, the lackluster role of government shocks post crisis in our estimation suggests that households' balance sheets have not fully healed.

To further appreciate the significance of financial shocks in the recent crisis, we calculate counterfactual paths for these shocks with which the economy would grow at its steady state rate from 2008.Q3 onwards; in these exercises, all the other shocks but one in consideration follow their estimated paths. The upper left panel of Figure 7 suggests that the Great Recession could have been averted if the economy had enjoyed better financial conditions. It is remarkable that nearly an

shocks for this exercise. Results for other variables are available in the appendix.

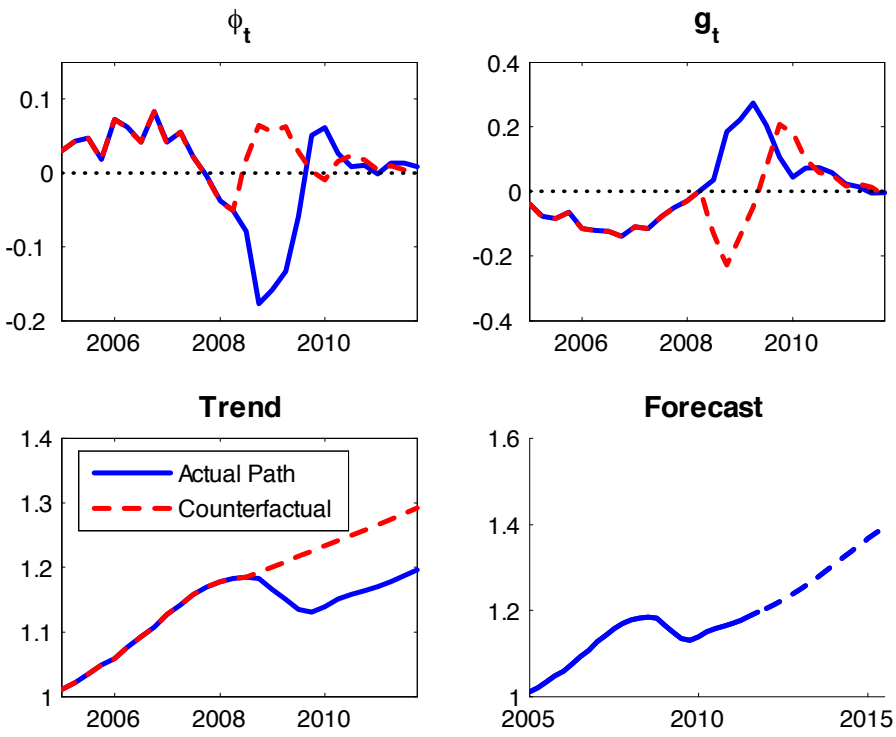

Figure 7: Liquidity, Government Spending, and Economy's Trend

average financial market which requires only a mild recovery of liquidity in the later half of 2008 would have been sufficient for the economy to avoid the Great Recession according to our fictional scenario.

The upper right panel in turn displays the government consumption shock required to keep the economy at trend. It tells us a similar story as with liquidity but with the opposite sign. Recall that government consumption shocks are contractionary in our model; hence, their decline, which is akin to a favorable shock to the households' exogenous income, pulls the economy back to the trend. The lower left panel in Figure 7 shows the actual and counterfactual trends in our model. It is evident that temporary shocks can cause a permanent shift in the economy's trend in our model, which is a great contrast to standard RBC models in which transitory shocks cause only transitory fluctuations around the trend. These results suggest that if we were able to affect the path of liquidity and/or income shocks, there seems to be some scope to ameliorate recessions fueled by financial shocks. In Guerron-Quintana and Jinnai (2014), we show that policies providing liquidity to entrepreneurs could alleviate the adverse effects of financial crisis. However, this analysis has the potential caveat that the data already incorporate the effect (if any) of the economic policies implemented during the recovery.

The break in the economy's trend forcefully brings the issue of how the trend would evolve in

the future. To this end, the forecast for the economy's trend 2012.Q1-2015.Q2 is displayed in the lower right panel in Figure 7. In the absence of persistent and favorable financial conditions (or other tailwind shocks such as productivity), the economy seems to be destined to transit, at least in the short run, along the new and depressed trend. According to our model, it is this pessimistic view toward the future that exacerbated the recession.

The Great Recession was remarkable in many dimensions, but what makes it different from other recessions? To answer this question, we see the Great Recession from a historical perspective. Figure 8 plots shock contributions for output growth in the previous four recessions in our sample (we combine the 1980 and 1981 recessions into one). The comparison reveals that one factor that makes the Great Recession unique is the sheer size of the shocks buffeting the economy. In none of the previous recessions, the combined effect of those shocks driving the recession accounted for more than 10 percentage points (compared to close to 25 percentage points in the last crisis). This finding concurs with Stock and Watson (2012)'s narrative that the Great Recession was driven by unusually large shocks coming from the same distribution of shocks prevailing during previous business cycles.

Output growth never goes above its mean after 2009 (see Figure 6). Our shock decomposition points to two elements behind this weak recovery post Great Recession. The first one is the persistence and deepness of the contribution of liquidity and government consumption disturbances to the crisis; note that no other recession saw such a persistent collapse of GDP growth driven by liquidity, government consumption, or any other shock. Second, tailwind shocks in the most recent recovery lack strength. This is in great contrast to the recoveries from the previous recessions; for example, all shocks but preference and technology consistently contributed to the recovery between the end of 1975 and the first quarter of 1977. During the early 1990s, the M.E.I. shock was the pulling force behind the growth above trend. More recently, financial and income tailwinds as captured by the M.E.I., liquidity, and government consumption shocks were pivotal in the 2000s recovery. These favorable shocks likely captured the loosening of financial markets pre-2008 crisis. A corollary of these observations is that if the economy benefited from a sustained sequence of favorable shocks as in the past four recessions, we might get back to the pre-2008 trend (or even above it). In general, in the class of endogenous growth models pioneered by Comin and Gertler (2006), if the economy is buffeted by a shock that is so large or so persistent that it shifts the trend, the economy needs an equally large shock, an equally persistent shock, or an unusual succession of shocks in the opposite direction to return to the original trend. Such favorable winds have not blown yet as implied by the depressed trend still prevailing as of the second quarter of 2015.

4.3 Roles of Endogenous Growth and Financial Frictions

Endogenous growth and financial frictions are two key elements of our model. To show this point, we estimate two alternative models using the same data set. The first model is an exogenous growth

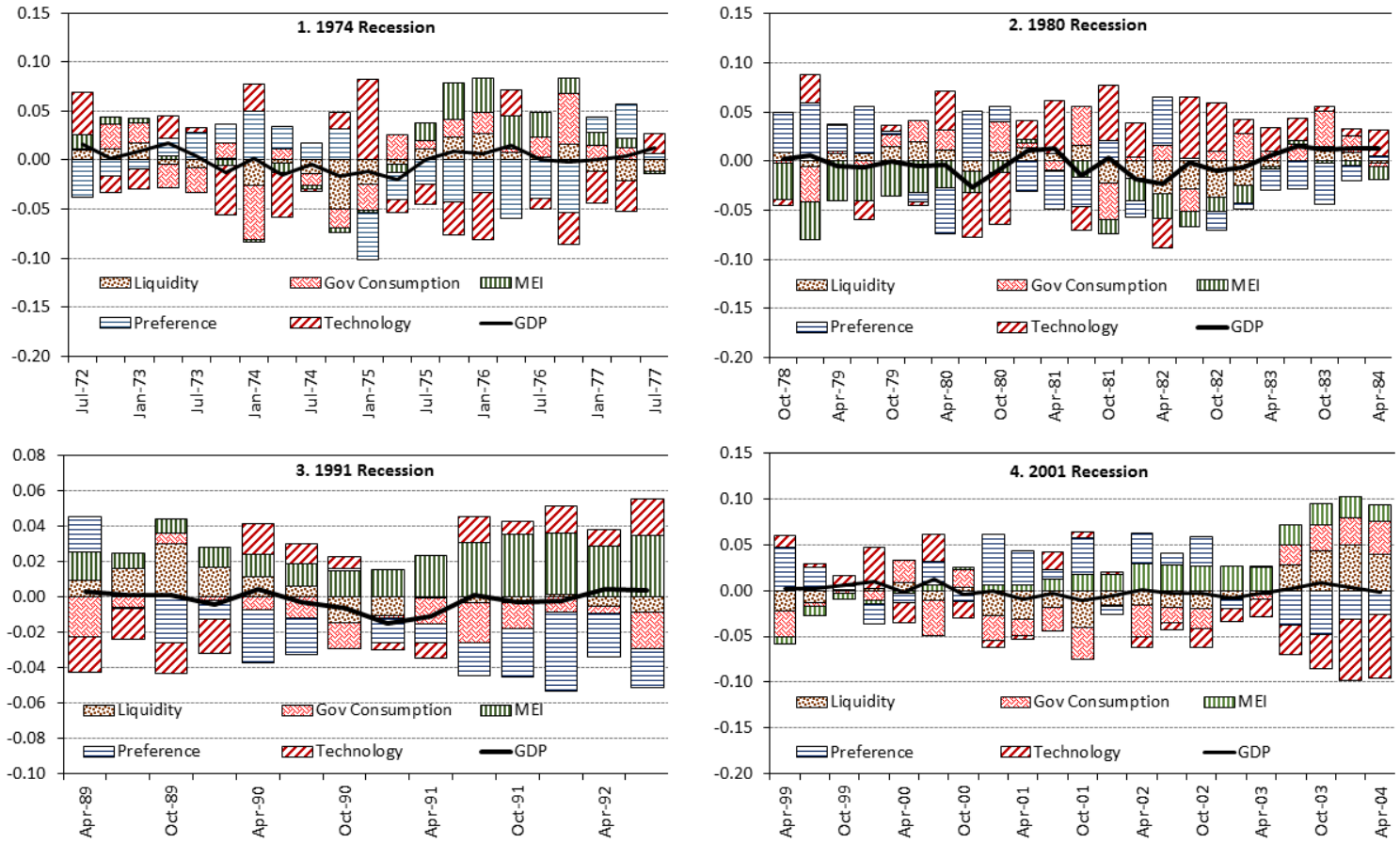

Figure 8: Shock Decompositions in Past Recessions

Table 3: Variance Decompositions in Alternative Models

		Δy	Δc	Δi	l	Δstmk	Δtfp			Δy	Δc	Δi	l	Δstmk	Δtfp
	(B)	0.27	0.17	0.22	0.64	0.53	0.59		(B)	0.08	0.07	0.32	0.03	0.02	0.02
ϕ	(EX)	0.03	0.01	0.08	0.01	0.00	0.00	χ	(EX)	0.13	0.22	0.87	0.04	0.00	0.04
	(W)	0.00	0.00	0.00	0.00	0.00	0.00		(W)	0.11	0.09	0.80	0.16	0.00	0.01
	(B)	0.24	0.26	0.23	0.03	0.01	0.19		(B)	0.00	0.00	0.00	0.00	0.22	0.00
A	(EX)	0.46	0.15	0.03	0.82	0.11	0.68	m	(EX)	0.00	0.00	0.00	0.00	0.86	0.00
	(W)	0.47	0.40	0.15	0.24	0.02	0.74		(W)	0.00	0.00	0.00	0.00	0.97	0.00
	(B)	0.15	0.19	0.13	0.28	0.21	0.15		(B)	0.00	0.00	0.00	0.00	0.00	0.03
g	(EX)	0.08	0.15	0.00	0.00	0.00	0.02	t	(EX)	0.00	0.00	0.00	0.00	0.00	0.26
	(W)	0.00	0.01	0.00	0.00	0.00	0.00		(W)	0.00	0.00	0.00	0.00	0.00	0.24
	(B)	0.26	0.31	0.09	0.02	0.01	0.02								
φ	(EX)	0.30	0.47	0.01	0.13	0.03	0.00								
	(W)	0.42	0.50	0.05	0.60	0.01	0.01								

model with the liquidity friction in investment, in which the endogenous product entry is removed, but the stochastic process of the technology shock A_t is modified to be non-stationary. In addition, we assume that there are workers and investors in the household, and only the investors can conduct investment in physical capital as in Kiyotaki and Moore (2012). The second model is an endogenous growth model without the liquidity friction, which is the same as the benchmark model except for calibration. Specifically, we assume that $\theta = 1$, with which innovations can be equity financed and therefore liquidity constraints never bind. The models are detailed in the appendix.

Table 3 shows that liquidity shocks (ϕ) are almost irrelevant for business cycles in the alternative models.[31] It explains 3% of output variation in the exogenous growth model (EX) and 0% of output variation in the model without liquidity friction (W), while the same shock explains 27% of the variation of output growth in the benchmark model (B). Interestingly, the explanatory power of the government consumption shock (g) is similarly reduced in the alternative models, confirming our previous discussion that the effect of this shock is amplified by both the liquidity friction and the endogenous growth mechanism. In contrast, the technology shock (A) gains prominence in both models; it explains 46% of output variation in the exogenous growth model and 47% of output variation in the model without liquidity friction, while the same shock accounts for only 24% of the output growth volatility in the benchmark model. Although the evaluation of these results is arguably subjective, it is undoubtedly undesirable that the alternative models heavily rely on measurement errors (m and t) to account for stock market variation and TFP variation.

Given the previous result, it is not surprising that shocks to the entrepreneurs' ability to fund projects, i.e., liquidity and government consumption, are nearly irrelevant to the Great Recession

[31] Notice that we did not report the variance decomposition for Stock and Watson's financial measure (sw) in Table 3 because it is trivial. Namely, sw is perfectly explained by ϕ in all the models considered in this paper.

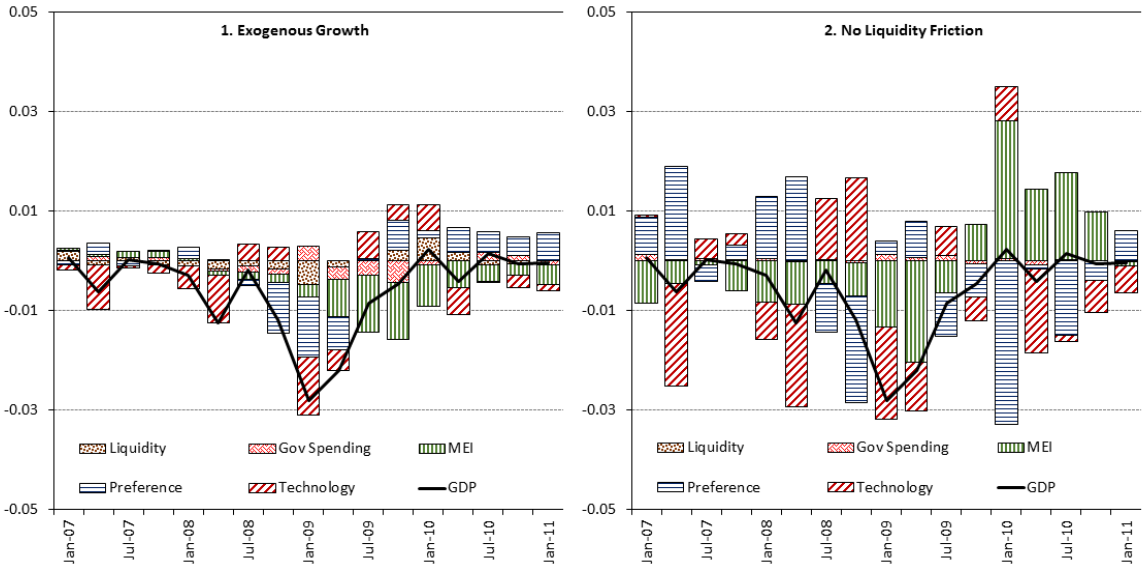

Figure 9: Shock Contribution in Great Recession: Alternative Models

in the alternative models. This can be seen in Figure 9, which plots the shock contributions in the alternative models.[32] Rather than financial disturbances, large exogenous productivity shocks were behind the collapse of the economy in 2008 and 2009. Similarly, the M.E.I. shock played an important role during the crisis; this is particularly so for the model without liquidity frictions in which the M.E.I. disturbance mimics the role of financial shocks. In sum, the alternative models give a drastically simple account; the Great Recession is nothing but a product of exogenous productivity shocks.

4.4 Importance of Shock Amplification

The current section clarifies the importance of shock amplification in our findings. In the first exercise, we increase the elasticity of $\delta'(u)$ evaluated at the steady state from 0.27 to 1. The amplification mechanism should be weaker when this parameter is higher because the cost of utilization rises quickly with the level of utilization. Impulse response functions to a liquidity shock in Figure 10 confirm that both the short-run boom and the long-run effect to the trend are much smaller when utilization is more costly (red dashed lines) than in the benchmark model (black solid lines). The impact on the short-run is largely expected, but the long-run effect may not because utilization

[32] Detailed historical decompositions and additional comparisons are in the appendix.

Figure 10: Responses to a Liquidity Shock; Less-Elastic Utilization (Red Dashed), Less-Elastic Labor (Blue Dotted), and Benchmark (Black Solid)

is often considered as a short-run propagation channel of shocks (e.g., Greenwood, Hercowitz, and Krusell (2000)). This result underscores the unique feature of our model; the dichotomy between the trend and the cycle does not hold, but they reinforce each other. Namely, a larger short-run boom leads to a higher trend, and a more optimistic view toward the future strengthens the short-run boom.

Table 4 shows the variance decomposition.[33] Compared to the benchmark model (rows labeled B), the explanatory power of the liquidity shock is greatly reduced whereas the explanatory power of the technology shock is greatly enhanced in the model with less-elastic utilization (U). Moreover, the latter model relies heavily on measurement errors. These implications are similar to the ones we saw in the previous section.

Next, we investigate the role of endogenous labor supply as a shock amplification mechanism. The elasticity of non-market hours ω is a crucial parameter; when ω is low, amplification is weak because the marginal rate of substitution of market hours for final goods (the right-hand side of equation (8)) quickly rises with the level of market hours, making market hours weakly responsive to shocks. In the benchmark model, we calibrate it at $\omega = 0.8$, which assumes a home production with elasticity of labor equal to the one of the production function in the market sector. Since the

[33] We did not report the variance decomposition for Stock and Watson's financial measure (sw) in Table 4 either because it is trivial.

Table 4: Variance Decompositions with Less-Elastic Utilization and Labor

		Δy	Δc	Δi	l	Δstmk	Δtfp			Δy	Δc	Δi	l	Δstmk	Δtfp
	(B)	0.27	0.17	0.22	0.64	0.53	0.59		(B)	0.08	0.07	0.32	0.03	0.02	0.02
ϕ	(U)	0.03	0.02	0.02	0.08	0.07	0.15	χ	(U)	0.10	0.08	0.58	0.25	0.01	0.02
	(L)	0.06	0.04	0.06	0.09	0.13	0.18		(L)	0.21	0.19	0.62	0.32	0.21	0.13
	(B)	0.24	0.26	0.23	0.03	0.01	0.19		(B)	0.00	0.00	0.00	0.00	0.22	0.00
A	(U)	0.48	0.45	0.30	0.27	0.08	0.66	m	(U)	0.00	0.00	0.00	0.00	0.80	0.00
	(L)	0.41	0.45	0.18	0.18	0.02	0.41		(L)	0.00	0.00	0.00	0.00	0.37	0.00
	(B)	0.15	0.19	0.13	0.28	0.21	0.15		(B)	0.00	0.00	0.00	0.00	0.00	0.03
g	(U)	0.00	0.04	0.00	0.07	0.00	0.01	t	(U)	0.00	0.00	0.00	0.00	0.00	0.13
	(L)	0.08	0.06	0.09	0.33	0.22	0.18		(L)	0.00	0.00	0.00	0.00	0.00	0.47
	(B)	0.26	0.31	0.09	0.02	0.01	0.02								
φ	(U)	0.39	0.41	0.09	0.33	0.03	0.03								
	(L)	0.24	0.26	0.04	0.07	0.05	0.05								

empirical evidence is scant on this respect, we reduce it to $\omega = 0.5$ for robustness check.

Both Figure 10 and Table 4 show that results are similar to the model with less-elastic utilization. Namely, both the short-run boom and the long-run effect on the trend are much smaller when labor is less elastic (blue dotted lines) than in the benchmark model (black solid lines); the explanatory power of the liquidity shock is greatly reduced, and the explanatory power of the technology shock is greatly enhanced in the model with less-elastic labor (L) relative to the benchmark model (B). Similar to the model with less-elastic utilization, the version with less-elastic labor relies more on measurement errors.

5 Conclusion

The shift in the U.S. economy's trend is one of the lasting legacies of the Great Recession. In our framework, this drift results from a combination of financial frictions and persistently adverse shocks. With these factors choking entrepreneurial activities, the economy slows down, leading to the break in the growth trend. The crucial question is then whether we will revert to the old trend. From our model's perspective, there are two possible scenarios. First, we are lucky and the economy is buffeted by good shocks (like during the early stages of the Great Moderation). Second, rather than waiting for random events, improving the financial strength of entrepreneurs seems a plausible path. We think of entrepreneurs as broadly capturing those agents and sectors driving growth in the economy. In the working paper version, we show that a lump-sum transfer to entrepreneurs during the Great Recession could have significantly reduced the depth and duration of the crisis. The American Recovery and Reinvestment Act was a step in this direction if it was used for helping entrepreneurs. Our analysis, however, reveals that the stimulus was too small and too late.

Our analysis is completely silent about important events of recent years such as the zero lower bound (ZLB) and the persistently low inflation. We abstract from these elements mostly because of tractability issues. From the work of Fernaldez-Villaverde, Guerron-Quintana, Kuester, and Rubio-Ramirez (Forthcoming) and Gust, Lopez-Salido, and Smith (2012), we learn that dealing with the ZLB is a treacherous business, even more if we try to estimate the model. Yet we conjecture that our main findings would survive in a nominal setup. Based on the insights of Christiano, Eichenbaum, and Rebelo (2011), the multiplier effect of the ZLB would probably reduce the size of the innovations needed to explain the economy post 2010 without affecting much the overall importance of frictions and shocks.

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