Financial Frictions, Trends, and the Great Recession

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Abstract

We study the causes behind the shift in the level of U.S. GDP following the Great Recession. To this end, we propose a model featuring endogenous productivity à la Romer and a financial friction à 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

Several years into the recovery from the Great Recession, it is becoming clear that real GDP is failing to recover. Namely, the level of U.S. output is growing at pre-recession growth rates, but the crisis seems to have impinged a shift upon the output level. Figure 1 shows the level and growth rate of real GDP over the past decade. Without much effort, one can see that the output level 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 output level never returns to the original trend.[2] With its economic significance, it is not surprising that this tepid recovery has spurred debate about the

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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.

causes and consequences of 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 failing to push the output level back to its original trend.[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 in the level 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. That is, the economy always reverts to its pre-shock trend, which is an unpleasant feature to study shifts in the trend. Alternatively, one could allow long-lasting drifts in the RBC model, but this is 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 and 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

[3]See the lively 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). A growing literature studies the same phenomenon in light of the concept of secular stagnation (Hansen (1939)). See Summers (2013) and Eggertsson and Mehrotra (2014).

[4]Financial markets were unusually tight. According to a 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 the notion 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 highly leveraged firms had to reduce employment, close down establishments, and cut back on investment, most likely because they were financially constrained. A detailed discussion of these empirical studies is in the appendix.

[5]Other economic factors might cause a permanent change in 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.

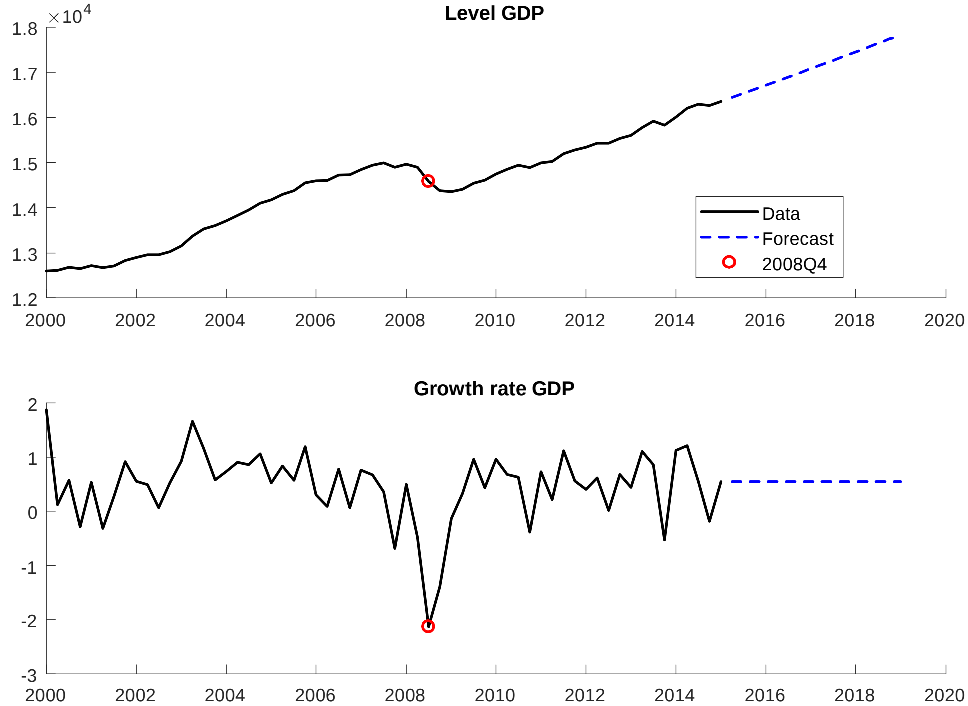

Figure 1: U.S. Real GDP

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 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 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

[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 empirical support for the permanent effects of financial crises, see Cerra and Saxena (2008).

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 as follows. Expecting higher aggregate productivity in the future, households increase consumption. At the same time, they find it optimal to increase investment sooner rather than later to avoid potentially large adjustment costs. A high capacity utilization rate makes simultaneous increases in both consumption and investment possible, and expands output and hours worked as well by shifting the labor demand schedule outward.

The other paper is Bansal and Yaron (2004) in the long-run risk literature in finance, who establish the condition 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. Crucially, 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.

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 a reduction in 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 the result that improving financial markets as captured by favorable liquidity and the 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. Compared to our baseline model, these alternative models give completely different accounts of the data. For example, in either of the two versions, exogenous shocks to productivity emerge as an essential player, accounting for almost half of the unconditional volatility of output growth as well as the Great Recession. Both liquidity and government consumption shocks play a very modest role. Furthermore, measurement errors rather than structural shocks account for the bulk of volatilities in stock market value and TFP in the alternative models. This result shows that both endogenous productivity and the financial friction are indispensable to the main findings in this paper.

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 (2017) and Kiyotaki and Moore (2012). Guerrieri and Lorenzoni (2017) study the effect of a credit crunch on consumer spending in a heterogeneous-agent incomplete-market model. Justiniano, Primiceri, and Tambalotti (2015) study the household sector's leveraging and deleveraging cycle in a model with a collateral constraint and two types of households. Our use of Kiyotaki and Moore's liquidity model does not mean that other elements 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)). We are close to Ajello (2014), who estimates a model with financial frictions in which competitive financial intermediaries transfer resources between entrepreneurs with heterogeneous 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. Del Negro, Eggertsson, Ferrero, and Kiyotaki (2017) also find that nominal frictions are important to resolve counterfactual responses in the stock market.

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. Guerron-Quintana and Jinnai (2015) report that the pace of innovative activities measured by R&D and patent data slowed down during the Great Recession, being consistent with our model's implication. Comin and Gertler (2006) discuss the unconditional correlation between R&D and aggregate TFP before the most recent financial crisis. Another related study is Queralto (2015), who introduces Comin and Gertler (2006)'s framework into a small open economy model to study the South Korean economy following the 1997 crisis.

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.[7]

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 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 member's role 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, reserves 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

[7] 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).

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.[8] $\delta(\cdot)$ 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 of 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.[9] 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. 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:

$$\underbrace{c_t^e + s_t + \underbrace{p_{n,t} n_{t+1}^e + p_{k,t} k_{t+1}^e}_{\text{gross asset purchases}}}_{\text{gross expenditure}} \tag{2}$$

$$= \underbrace{\left(1 - \underbrace{\tau_p}_{\text{tax}}\right)\left(\underbrace{\Pi_t n_t}_{\text{dividend}} + \underbrace{u_t R_t k_t}_{\text{rental}}\right) + \underbrace{p_{n,t}(1-\delta_n) n_t + p_{k,t}(1-\delta(u_t)) k_t}_{\text{resale value}} + \underbrace{p_{n,t}\vartheta_t s_t}_{\text{IPO}} + \underbrace{\tau_{tr,t}}_{\text{transfer}}}_{\text{gross after-tax income}}.$$

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

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

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, encompassing 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:

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

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 for 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 for herself. Effectively, these constraints introduce lower bounds to the equity holding and capital holding of an entrepreneur at the closing of the markets:

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

and

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

ϕ_t is an exogenous random variable representing shocks to asset liquidity.[10] 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

[10] Brunnermeier, Eisenbach, and Sannikov (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.*

of the household chooses instructions to its members to maximize the value function defined as

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

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 the worker's original preference is given by

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

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

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

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 the 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 for entrepreneurs. Namely, entrepreneurs' 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 holds. 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

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

It equates the marginal rate of substitution to the after-tax wage rate.[11] 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 $\mu_t^w = \left[c_t^w + \frac{\varphi_t}{\omega}(\Psi_t)(1-l_t)^\omega\right]^{-\frac{1}{\psi}}$. The optimality condition equates the costs and the benefits of investment.

The optimality condition for product development is

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

The intuition is as follows. An entrepreneur can increase 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 $\beta\mathbb{E}_t[\partial v(q_{t+1};\Gamma_{t+1},\Theta_{t+1})/\partial n_{t+1}]$ 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

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

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

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

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, the entrepreneur's marginal utility of consumption is greater than the worker's in equilibrium.

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

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

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

and

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

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 the capacity utilization rate is given by

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

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 elasticity, 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

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

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

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

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

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

Notice that because $\vartheta_t \left(\sigma_e s_t \right) = \zeta \left(\sigma_e s_t \right)^{\eta} \left(N_t \right)^{1-\eta}$, 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 a permanent effect on the economy's trend 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, which we call the government consumption shock. Furthermore, the government keeps its budget balanced:

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

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 our findings much. 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 than assuming an ad hoc income shock directly hitting entrepreneurs' balance sheets. Third, government consumption shocks are conventional in the literature. Fourth, we review some of the empirical literature on government multipliers to show that our results are not that surprising.[12]

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 $L_t = \sigma_w l_t$. The 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 $\left(1 - \delta\left(u_t\right)\right) K_t = \sigma_e k_{t+1}^e + \sigma_w k_{t+1}^w$ 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

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

where Z_t is given by $Z_t = \left(\bar{A}\right)\left(A_t N_t\right)$, 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

[12] In the appendix, we relax the balanced budget assumption to show that our results do not rely on this simplification.

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 via the equation $\mathcal{Y}_t = \left(1 - \frac{\xi}{\nu}\right) Y_t$. 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

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

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

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

We do not include investment in 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 point the asset markets are already closed. We define total factor productivity (TFP) as

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

This is a standard definition and, importantly, consistent with Fernald (2014)'s TFP measure. 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 of TFP. It is worth noticing that we also tried an alternative specification that controls for capacity utilization in both the model and the data. Since the capacity-adjusted TFP differs from the unadjusted series in the data around 2008, it is important to assess any implications of the alternative TFP measures. It turns out that the results from this version are consistent with what we report next.[13]

[13] The results are available upon request. We thank an anonymous referee for suggesting that we check this

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

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

where ρ_ς and σ_ς are the persistence and standard deviation of the stochastic process. The innovation $\varepsilon_{\varsigma,t}$ is assumed to follow the standard normal 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, in particular the stochastic processes. In this way, we put the structural shocks at the forefront of our analysis.

3.1 Calibrated parameters

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 values used in the literature (Bilbiie, Ghironi, and Melitz (2012) and Kung and Schmid (2015)). The capital depreciation rate in the steady state δ_k is set to 0.03, again, in line with the value used in the literature (e.g., Barsky, Basu, and Lee (2015)). 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 rate, u, is set to 1.0.

The following parameters are calibrated either using the model implications or targeting empirical moments. The marginal capital depreciation rate in the steady state, δ', is pinned down by the utilization 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's share in the value-added output in the steady state is the standard choice of 0.2. The scale parameter in the product innovation function, ζ, the labor-augmenting technology

alternative specification.

shock in the steady state, A, and the preference shock in the 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 stead- 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 empirical targets using their steady-state counterparts: (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), who define it as the ratio of the compensation of employees over gross national product.[14] Investment is narrowly defined as business investment in structure and equipment, because tangible capital in the business sector is the closest concept to physical capital in our model. 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. But we want to note that there is little consensus on the empirically reasonable size of intangible investment.[15] Our main results are robust to reasonable variations to the calibration targets, too.

Finally, 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 model's predictions match the empirical targets.

3.2 Estimated parameters

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 the 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 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. That is, R&D is

[14] Koh, Santaeulalia-Llopis, and Zheng (2016) show that intellectual property products (IPP) capital accounts for the secular decline of the U.S. labor share (Elsby, Hobijn, and Sahin (2013)). Our model is consistent with their findings if we allow time-varying ξ. Namely, a larger value of ξ implies a smaller aggregate labor share, while it is neutral to the traditional labor share that includes only income from traditional capital but excludes income from IPP capital.

[15] In the previous work, the implied share of R&D in GDP can be as high as 15% and 16% (Atkeson and Burstein (2011) and Bilbiie, Ghironi, and Melitz (2012), respectively), or as low as 1% in Comin and Gertler (2006). Our empirical target is based on Nakamura (2003).

excluded from investment, and output is adjusted so that it reflects the broader measure of R&D. The sample covers 1970.Q1 - 2011.Q4.[16] 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 on our empirical analysis.

Our measure of financial conditions is based on the first principal component of the liquidity/financial risk shocks considered by Stock and Watson (2012).[17] 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 a one-percentage-point change in the model corresponds to a 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.

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.[18] 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 with 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 the heterogeneity of both capital goods and workers, as well as labor quality, into account to refine his technology measure. But their vari-

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

[17] 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.

[18] 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.

ations 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 Fernald's admirable effort 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* normally distributed shocks without persistence.

3.3 Estimation approach and priors

This section provides an overview of our estimation approach; details are in the appendix. First, we use data on quarterly growth rates for output, consumption, investment, the stock market valuation, and TFP. The financial measure and labor are taken in levels because they are stationary. Second, we de-trend the model and solve it via first-order perturbation methods. Once the model is solved, we construct the model-implied growth rates for the equivalent growth variables in the data. Labor and the liquidity process are taken directly to the data because they don't display a trend in our model.

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.

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	Values in the Literature	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 Elasticity			
ν	2.00	Investment Share			
σ_e	0.02	R&D Share			

3.4 Posteriors

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 display 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 $\alpha = 0.2$ 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 2 shows that a positive liquidity shock (loosening the liquidity constraint) 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 log-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 downward 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 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. 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).[19] 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

[19] Jaimovich and Rebelo (2009) offer a solution to a comovement problem in the news shock literature. A standard neo-classical growth model predicts that the arrival of 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 effects on labor supply. Note that our model has all of them.

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).[20] 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.[21] [22]

The counterfactual response of the stock market is perhaps a deeper problem because it is robust to a wide range of specifications (Shi (2015)).[23] 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.[24]

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 due to the endogenous stochastic discount factor. 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

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

[21] 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 nonmarket hours, making the prediction relatively robust to parameter specifications.

[22] The slowdown of output growth between 3 and 5 years after the liquidity shock is caused by both the investment adjustment costs and the variable capacity utilization rate. Note that investment growth slows down in this period. Because the price of capital is positively related to the difference between current and future investment growth, which we can see by linearizing the household's first-order optimality condition for investment, the price of capital is relatively high in this period. Because a high capital price means high opportunity costs of raising utilization, the utilization rate is lowered, slowing down output growth.

[23] 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.

[24] 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 a result, 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.

of a constant discount factor carries over to 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 2 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 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 could agree upon a mutually beneficial sharing of the burden (a reduction in 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.

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 high frequency may produce medium-frequency oscillations.

We briefly comment on the remaining impulse responses, summarized in Figure 3, 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, and Rebelo (1988)). A preference shock (increasing the productivity of home production) causes a recession characterized by simultaneous decreases in output, investment, consumption, hours worked, and stock market value, as the household substitutes nonmarket 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 their transitory nature;

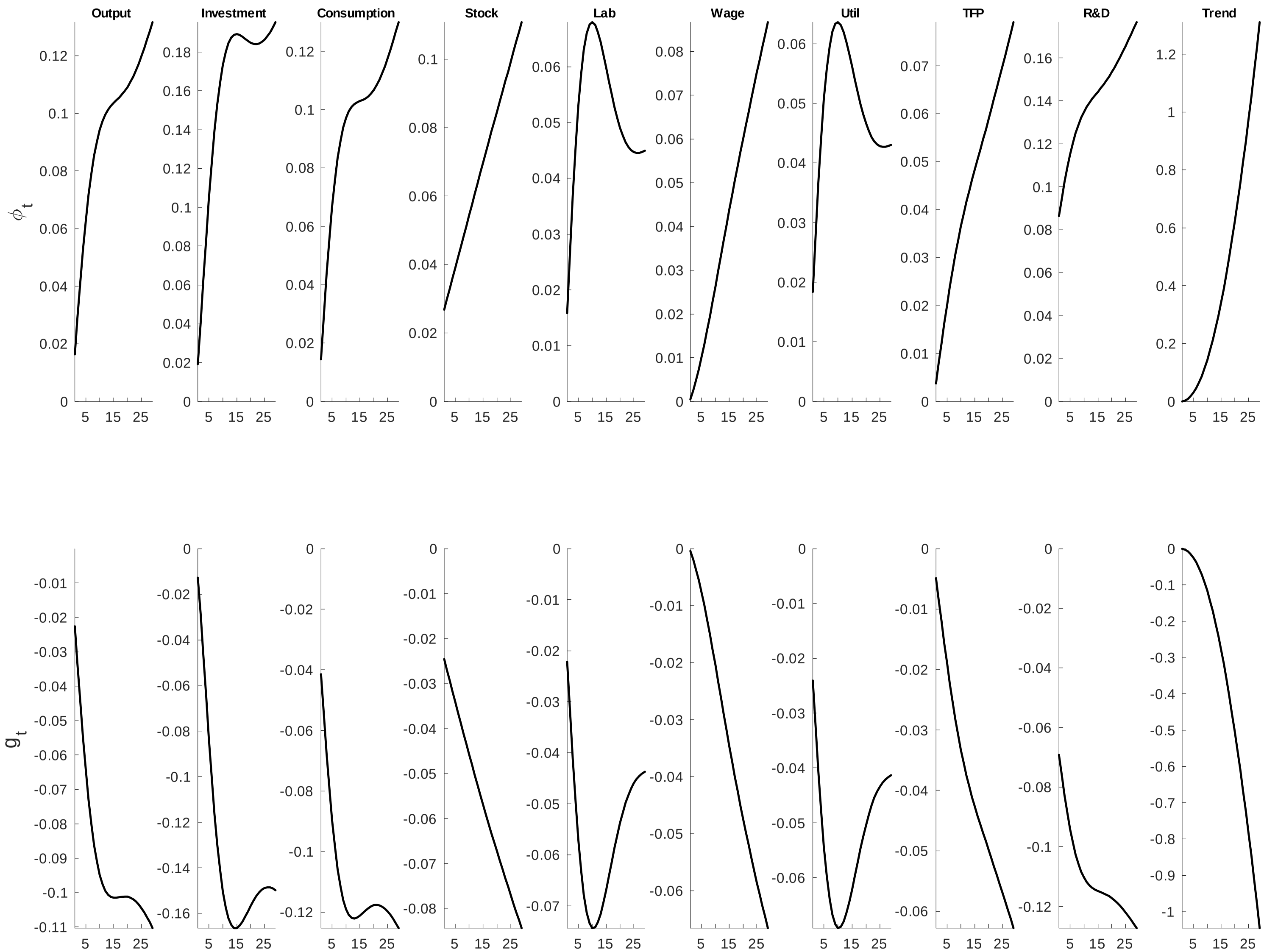

Figure 2: Impulse Responses to Liquidity Shock and Government Consumption Shock

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

it is clear that the economy largely reverts, or at least starts to revert, to the original trend within 5 years after the shocks.

Readers may wonder why the impulse responses to a productivity shock show a pronounced drop in output and other variables following the initial boom. The reason is that households increase investment after a positive productivity shock because additional capital will allow them to enjoy both consumption and leisure even after the exogenous productivity gain fades away. In our model, however, lump-sum transfers fluctuate with the aggregate economy, meaning that transfers are large when exogenous productivity is high, but later they decrease because exogenous productivity returns to a normal level and households having accumulated capital are about to enjoy leisure at the time. But transfer payments affect entrepreneurs' liquidity, and in addition, they are lump-sum. So a decline in transfers acts like an exogenous negative liquidity shock, causing a drop in output.

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 the variation in output growth (Δy) over the business cycle.[25] 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 stock market value (m) and TFP (t) pick up some volatility in the data ($\Delta stmk$ and Δtfp).

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

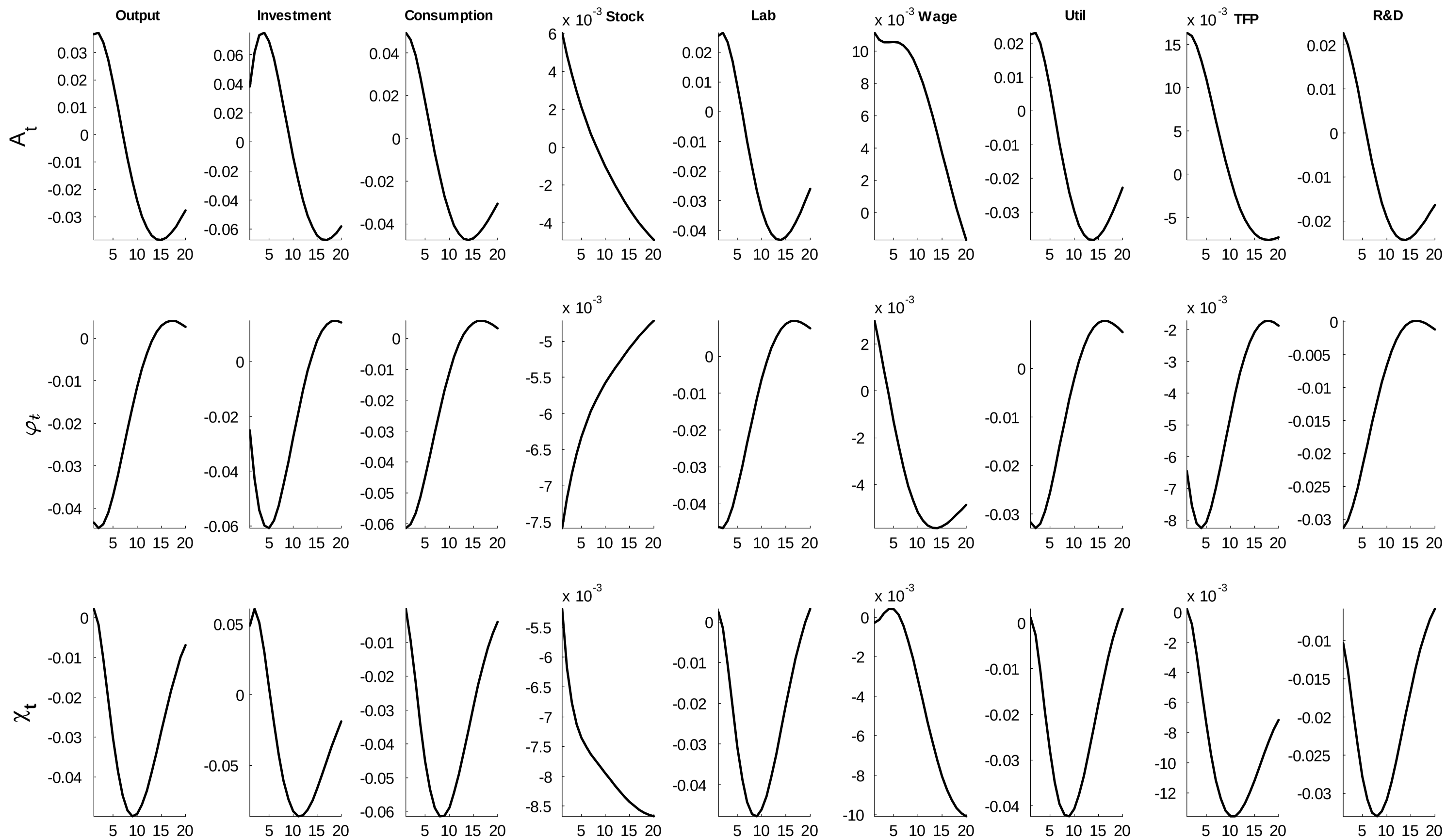

Figure 3: Rest of Impulse Responses in Baseline Model

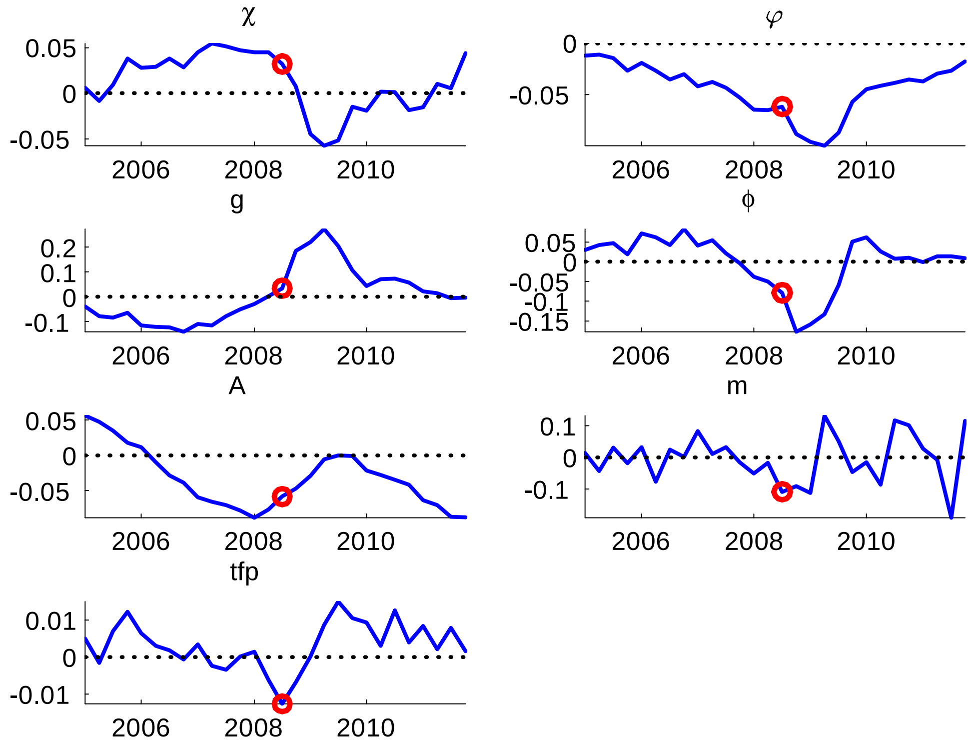

Figure 4: Smoothed Shocks during Great Recession

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 4 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.[26] Both liquidity and government consumption shocks in 2008.Q4 were unusual in size, more than two standard deviations away from the mean.[27] Our estimation, however, uncovers the fact that the economy embraced some favorable shocks as well. That is, the preference shock (φ) induced households to substitute nonmarket 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-skill workers.

Figure 5 helps us to understand how each shock contributed to the Great Recession. We compute

[26]Interestingly, 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).

[27]The density plot is available upon request.

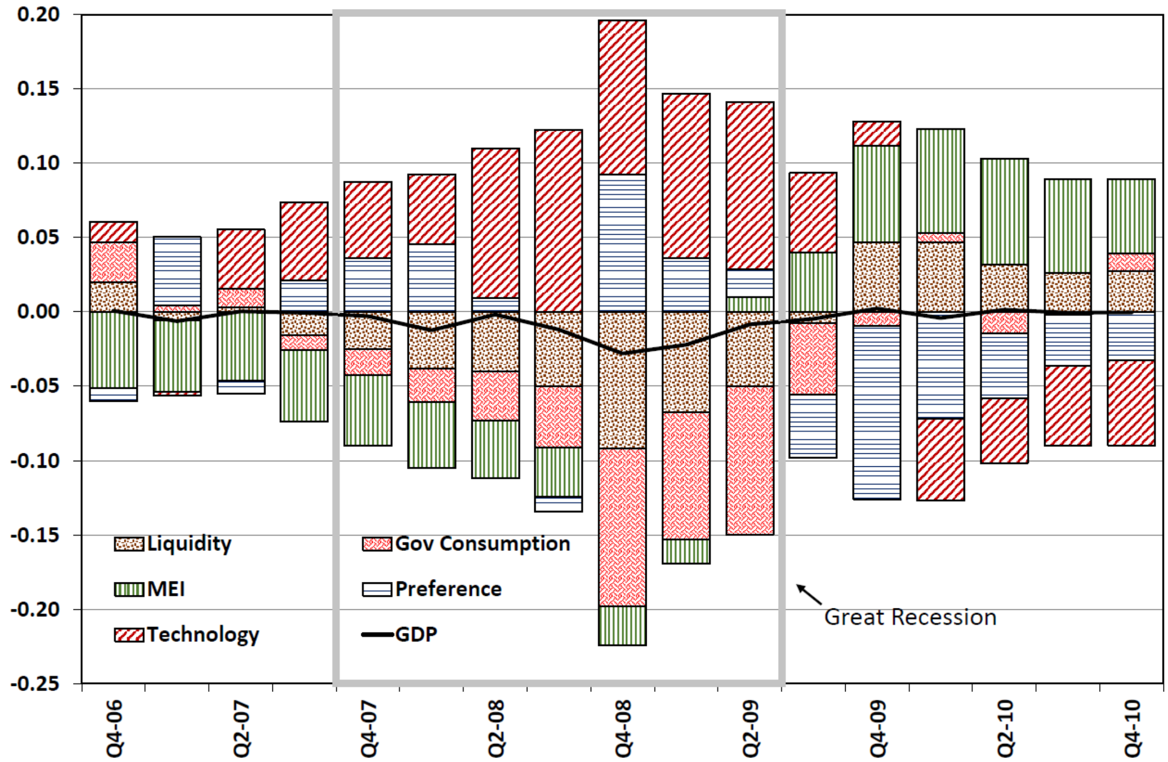

Figure 5: Shock decomposition during Great Recession.

the path for output growth if only one shock is the driver of the economy at a time, and stack them in bar charts.[28] It is clear that both the liquidity shock and the government consumption shock 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 imply 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 government consumption decreases the households' exogenous income. We conjecture that a sharp reduction in housing net worth, or at least the part of it that is due to factors exogenous to our model such as mortgage fraud (Mian and Sufi (2015)), may be captured as a rise in 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 onward. In these exercises, all the other shocks but the one under consideration follow

[28]Mechanically, we shut down all shocks but one and simulate the economy starting in 1971. We use the smoothed shocks for this exercise. Results for other variables are available in the appendix.

their estimated paths. The upper left panel of Figure 6 suggests that the Great Recession could have been averted if the economy had enjoyed better financial conditions. It is remarkable that a nearly average financial market, captured by 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 story similar to that of 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 6 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. This finding is in great contrast to standard RBC models in which transitory shocks cause only transitory fluctuations around the trend. Our 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 crises. 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 6. 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 7 plots the contributions of shocks to 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 did the combined effect of those shocks driving the recession account 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.

According to our estimate, the 1974 recession was initially driven by government and technology shocks and later by preference and liquidity shocks. In reality, the recession was triggered by OPEC's oil embargo. Since our model does not have a formal oil sector, our estimation approach attributes the crisis to shocks in different parts of the economy. For instance, the preference and government

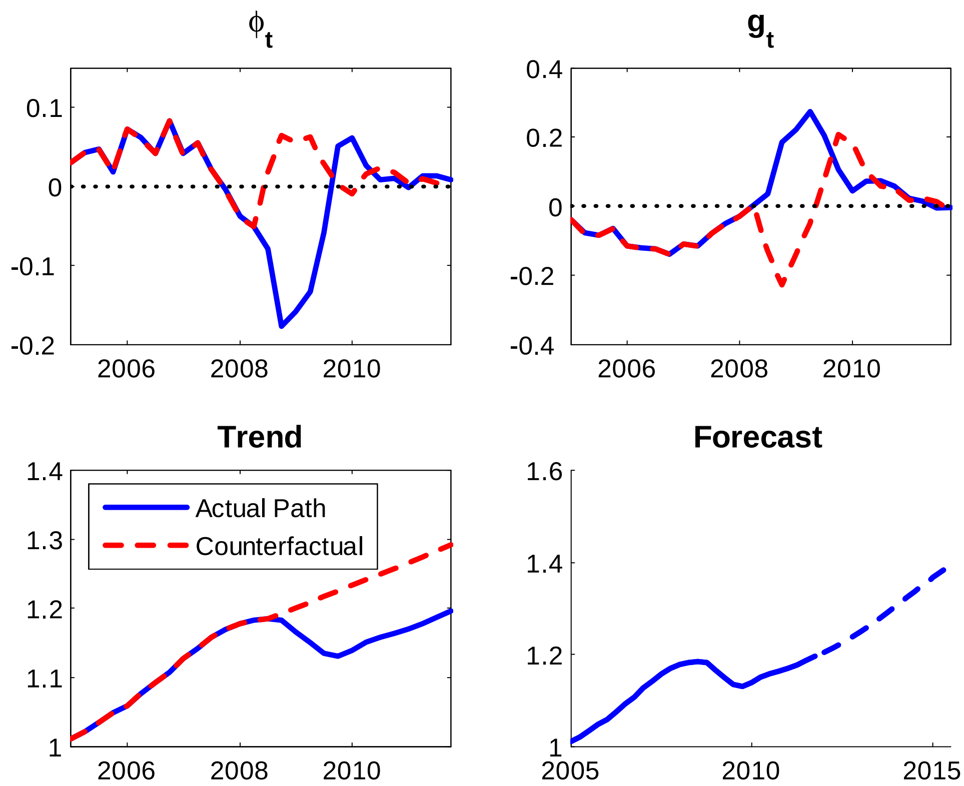

Figure 6: Liquidity, Government Spending, and Economy's Trend

shocks could be capturing the contraction in consumers' spending due to high gas prices. Similarly, the bad technology shock could capture increasing costs faced by firms, again related to expensive oil.

Output growth never goes above its mean after 2009 (see Figure 5). Our shock decomposition points to two elements behind this weak recovery after the 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 recovery during the 2000s. These favorable shocks likely captured the loosening of financial conditions 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 On Government Spending Shocks

In this section, we expand our discussion of government consumption shocks. According to our estimation, they were negative contributors to the Great Recession. Both the estimated path of the shock and the fiscal multiplier are crucial for this result. So we turn to each of them.

One way of assessing the role of government shocks in our findings is to discipline them by using actual data in the estimation step. However, this approach requires adding an additional shock to the model, which would unnecessarily complicate it and blur the interpretation of other shocks – recall that there are already 7 shocks in the model. Alternatively, we can check the plausability of the estimated government shocks by comparing the estimated path of these shocks from the model with the relevant object in the data, which is the government-spending-to-GDP ratio (see section 2.5).

Figure 8 plots the government shock in the model (black line, right axis) and the government-spending-to-GDP ratio (blue solid line, left axis) side by side. To the naked eye, they look remarkably similar; that is, our model delivers data-consistent government shocks. The reason behind

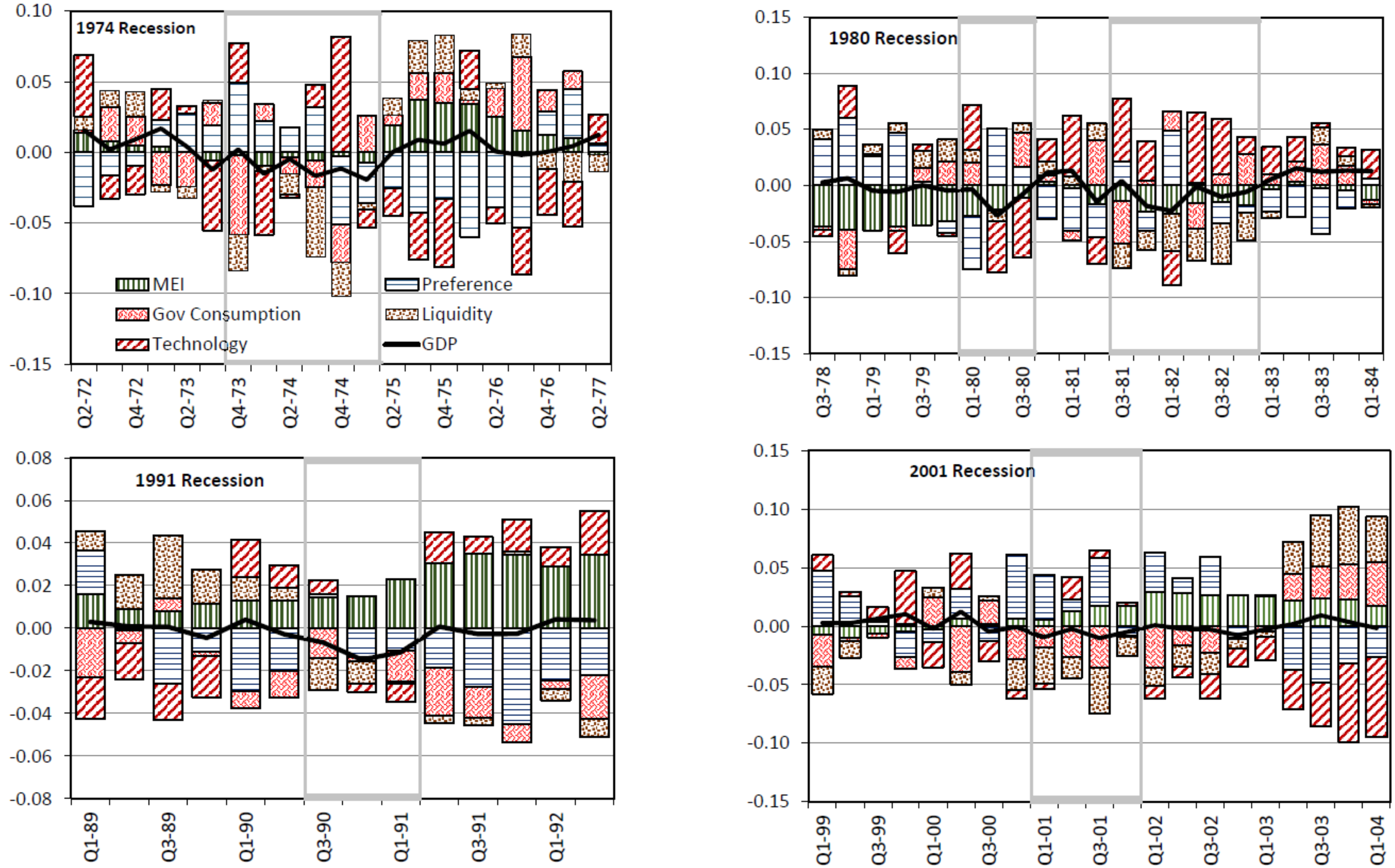

Figure 7: Shock Decompositions in Past Recessions

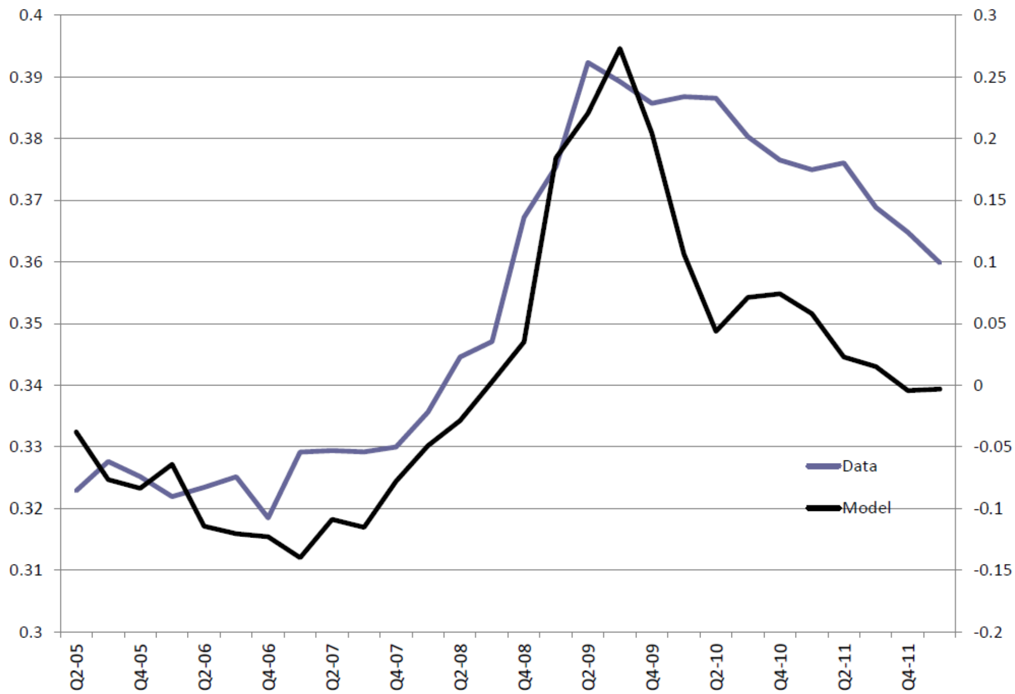

Figure 8: Government Shocks in Data and Model

this surprising finding is simple. In the model, government shocks translates into taxes in the entrepreneur's budget constraint, limiting her funding ability. Since the Great Recession was a period of scarse funding, this is captured in our model by a decline in liquidity and higher taxes levied on entrepreneurs. But higher taxes allow more government spending in the model, which precisely coincides with higher spending in the data. We should note that although the model and data have government expenditures above trend, they may reflect different aspects of the recession: countercyclical fiscal policies (data) and deteriorating funding conditions (model).

We now turn to the fiscal multiplier. It is negative in our model, which may sound counterintuitive at first. But we document that it has been equally argued in the empirical literature that the government spending shock can cause a contraction or expansion in the economy.[29] To begin with, Leeper, Traum, and Walker (2011) report that fiscal multipliers for output in the literature go from -0.26 to more than 1 on impact. In the long run, the multipliers fluctuate between -1.0 and 1.4.

The closest evidence to our paper is provided by Mountford and Uhlig (2009). These authors consider a sign approach in a VAR framework to identify the effects of government spending changes in the United States. One of the cases requires that the government budget be balanced, which is consistent with our model's assumption. Under this restriction, the authors report that on impact GDP barely moves following a government spending shock, but thereafter, the shock causes an overall contraction with output, consumption, investment, and real wages declining. Importantly, these negative relation between the shock and economic activity is found to be significant both in

[29] Guajardo, Leigh, and Pescatori (2011) is a comprehensive review.

the short and long run. We take their findings as an exogenous validation of the plausability of the multiplier in our model.

In an influential work, Ramey (2011) adopts a narrative approach, finding that an increase in government expenditure in the U.S. leads to fairly persistent declines in both consumption and real wages. Furthermore, she finds that government expenditure shocks identified using standard VARs and data on government spending forecasts from the survey of professional forecasters marginally raises GDP on impact. After that, there is a persistent recession in the economy as captured by the decline in output, consumption, investment, and real wages.

Alesina and Ardagna (2010) and the several references therein argue that fiscal adjustments (deficit reductions) can be expansionary. They adopt an event approach to identify large fiscal adjustments and stimuli in OECD countries. These large fiscal events are defined as those years in which the primary deficit is adjusted "by at least 1.5% of GDP." They find that during unsuccessful fiscal adjustments, GDP growth in the G7 group is negatively correlated with the adjustment. That is, unsuccessful fiscal consolidations can lead to an economic expansion, which implies a negative fiscal multiplier. Finally, Blanchard and Perotti (2002) use a structural VAR and event studies, finding that investment is negatively correlated with government spending shocks, which is consistent with our model (Figure 2). Based on these empirical evidence, we consider that negative fiscal multiplier should not be dismissed too easily as a possibility.

4.4 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 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.[30] It explains 3% of output variation in the exogenous growth model (EX) and 0% of output variation in the model a without liquidity friction (W), while the same shock explains 27% of the variation in 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

[30] 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.

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								

models; it explains 46% of output variation in the exogenous growth model and 47% of output variation in the model without a liquidity friction, while the same shock accounts for only 24% of 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 in the alternative models. This can be seen in Figure 9, which plots the shock contributions in the alternative models.[31] 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.

4.5 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 on the trend are much smaller when utilization is more costly (red dashed lines) than in the benchmark model (black solid lines). The

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

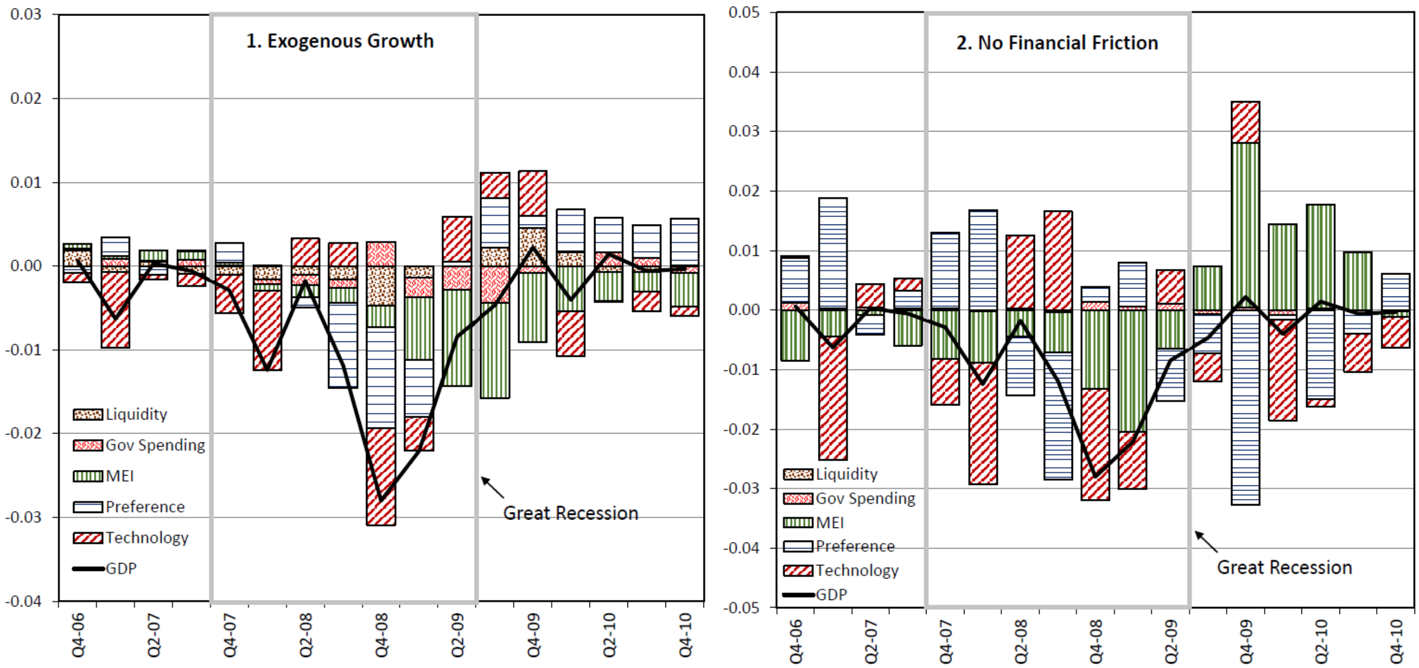

Figure 9: Shock Contribution in Great Recession: Alternative Models

impact on the short run is largely expected, but the long-run effect may not be expected because utilization is often considered as a short-run amplification 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.[32] 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 nonmarket 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 home production with an elasticity of labor equal to that of the production function in the market sector. Since the empirical evidence is scant in this respect, we reduce it to $\omega = 0.5$ for a robustness check.

Both Figure 10 and Table 4 show that results are similar to those in the model with less-

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

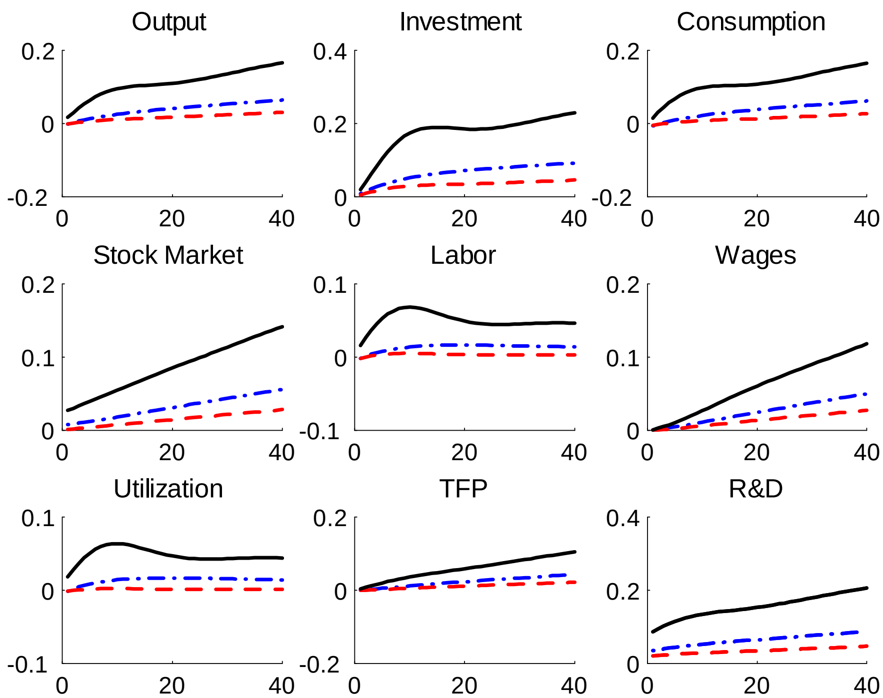

Figure 10: Responses to a Liquidity Shock; Less-Elastic Utilization (Red Dashed), Less-Elastic Labor (Blue Dotted), and Benchmark (Black Solid)

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

		Δy	Δc	Δi	l	Δstmk	Δtfp			Δy	Δc	Δi	l	Δstmk	Δtfp
ϕ	(B)	0.27	0.17	0.22	0.64	0.53	0.59	χ	(B)	0.08	0.07	0.32	0.03	0.02	0.02
	(U)	0.03	0.02	0.02	0.08	0.07	0.15		(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
A	(B)	0.24	0.26	0.23	0.03	0.01	0.19	m	(B)	0.00	0.00	0.00	0.00	0.22	0.00
	(U)	0.48	0.45	0.30	0.27	0.08	0.66		(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
g	(B)	0.15	0.19	0.13	0.28	0.21	0.15	t	(B)	0.00	0.00	0.00	0.00	0.00	0.03
	(U)	0.00	0.04	0.00	0.07	0.00	0.01		(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
φ	(B)	0.26	0.31	0.09	0.02	0.01	0.02								
	(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								

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 persistently low inflation. We abstract from these elements mostly because of tractability issues. From the work of Fernandez-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 so 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 since 2010 without affecting much the overall importance of frictions and shocks.

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