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# INVESTMENT-SPECIFIC SHOCKS, BUSINESS CYCLES, AND ASSET PRICES

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**Abstract**

This paper proposes and tests a new source of time variation in real investment opportunities, namely long-run shocks to the productivity of the investment sector, to explain the joint behavior of macroeconomic quantities and asset prices. A two-sector general equilibrium model with long-run investment shocks and wage rigidities produces both positive co-movement among key macroeconomic variables and a sizable return volatility differential between the investment and consumption sector. Moreover, positive long-run investment shocks are associated with low marginal utility and thus command a positive risk premium. We test our model using data on sectoral TFP and find evidence in support of our theoretical predictions.

**Keywords:** General Equilibrium Asset Pricing, Production Economy, Long-Run Risk, Investment-Specific Shocks, Wage Rigidities.

**JEL:** E32, G12.

# 1 Introduction

Recent research has shown that investment-specific shocks play a key role in explaining the dynamics of business cycles and asset prices.[1] Typically, in the associated equilibrium models, investment-specific shocks affect the formation of new capital goods by changing the marginal efficiency of new investments (MEI) and, thus, they are often referred to as MEI shocks. Although this approach contributes a great deal to our understanding of the role of investment-specific shocks, it leaves some questions open. First, models that attribute a central role to MEI shocks tend to produce a counterfactual negative co-movement among macroeconomic variables (the so-called "co-movement puzzle"). Second, with few exceptions, this literature focuses on the ability of investment-specific shocks to explain either macroeconomic dynamics or time-series and cross-sectional properties of stock returns. The joint implications of investment-specific shocks for asset prices and macroeconomic quantities are, however, not yet fully understood and appreciated. We argue that a consistent explanation of macroeconomic co-movements, relying on investment shocks, should also be able to provide a reasonable fit for key asset pricing moments and the dynamics of stock returns, and vice versa.

In this paper we propose a different source of time variation in investment opportunities, namely long-run risk (LRR) in the total factor productivity (TFP) of the investment sector, and analyze its performance with respect to the two issues outlined above. We introduce LRR in a general equilibrium model with two sectors (consumption and investment), assuming that the TFP processes of both sectors are driven by short-run (SR) and long-run (LR) components. We show, both theoretically and empirically, that our decomposition of investment-specific shocks into SR and LR components makes a substantial

[1] The different strands of literature on investment-specific shocks are summarized in Section 2.

contribution towards understanding and solving the issues described above.

The co-movement of macroeconomic variables can be quantified in several ways. We start by looking at impulse response functions from our model and find that only SR investment shocks are responsible for the co-movement puzzle while LR investment shocks do not induce any negative co-movement between macroeconomic quantities. Moreover, in the long run (from about 5 quarters after the shock onwards), the responses of macro variables to LR investment shocks are all positive. The intuition behind this result is as follows. SR investment shocks increase the *current* profitability of the investment sector relative to the consumption sector. As a result, they naturally generate a substitution effect that induces households to reallocate resources towards the investment sector, thus inducing a negative co-movement among macroeconomic variables. Differently, LR investment shocks affect the *future* profitability of investment. In addition to the substitution effect, positive news about future investment profitability generate an additional wealth effect that creates positive conditional co-movement among macroeconomic variables in the long run.

The conditional analysis using impulse responses illustrates only one aspect of the co-movement puzzle. The unconditional correlation of macro quantities, which comprises their response to all shocks in the economy, represents the other equally important aspect. Since SR shocks are quantitatively more important for unconditional correlations, our baseline model with SR and LR shocks still suffers from an unconditional co-movement puzzle. The typical way to fix this is to assume rigidities of some kind, for instance wage rigidities, and we follow the same route in this paper. However, since we do not include MEI shocks, which exacerbate the co-movement puzzle, the degree of wage rigidities necessary to match empirical moments in our benchmark model is much smaller and more realistic than in a model with MEI shocks.

The degree of wage rigidities necessary to make unconditional correlations positive is important because wage rigidities induce a trade-off between matching macroeconomic quantities and matching the equity return volatilites of the two sectors. More specifically, high wage rigidities imply a low volatility spread between the investment and consumption sector. First and foremost, they impair the ability of the productive sector to react to macroeconomic shocks and thus make firms' cash flows riskier. On top, however, this additional cash flow risk spills over from the investment sector to the consumption sector through the formation of capital goods, and so the increase of the consumption sector volatility is higher than that of the investment sector volatility, which makes the volatility spread unrealistically low. LR investment risk offers a way out of this tension. It improves the model's ability to generate realistic properties of sectoral stock returns while at the same time not inducing negative co-movement among macroeconomic variables.

MEI shocks also have the potential to induce a high volatility spread between the investment and consumption sector as Papanikolaou (2011) shows. However, we document that MEI shocks induce negative co-movement between consumption and investment growth. From this point of view, LR investment shocks are, therefore, better able to jointly improve the dynamics of macroeconomic quantities and asset prices. The ability not to generate negative co-movement implies that LR investment risk needs to be associated with only a moderate degree of wage rigidities in order to obtain positive unconditional correlations among macroeconomic variables, thus preserving the asset pricing properties of the model.

We also verify the main economic mechanism of our model empirically. We estimate the TFP processes of the consumption and the investment sector and extract their LR component by applying a standard state-space approach to sectoral TFP data. We then estimate the dynamic impulse responses of consumption, output, investment, and labor to SR and LR sectoral shocks in a VAR model and find that LR investment shocks have a positive long-run impact on macro variables as predicted by our theoretical model. Moreover, we document that the SR and LR components of sectoral TFP are also quantitatively important. For instance, over a horizon of one quarter, SR shocks (together) account for 58 percent while LR shocks account for 12 percent of output fluctuations. The predictive power of SR shocks tends to decrease with the forecasting horizon while the predictive power of LR shocks tends to increase: over a horizon of 20 quarters SR shocks account for 48 percent while LR shocks account for 16 percent of output fluctuations. Our evidence also suggests that LR investment shocks are quantitatively more important than LR consumption shocks in explaining macroeconomic fluctuations. In fact, we find that LR investment shocks explain a fraction of output variance that can be up to 13 times bigger than the fraction of output variance explained by LR consumption shocks.

The empirical identification strategy is also useful to test the cross-sectional asset pricing implications of LR investment shocks. In our model, these shocks are associated with economic states with low marginal utility and thus command a positive risk premium. We confirm this prediction empirically. Using the standard two-stage Fama-MacBeth procedure we document that LR investment shocks are priced in the cross-section of stock returns and carry a positive and significant risk premium. These results taken together suggest that LR investment risk is a plausible candidate to explain not only fluctuations of macroeconomic quantities, but also key asset pricing moments.

The remainder of the paper is organized as follows. Section 2 discusses the relevant literature on this topic. Our two-sector production economy is presented in Section 3 and its quantitative implications are analyzed in Section 4. Section 5 provides empirical evidence on the main mechanism of the paper. Section 6 documents the cross-sectional asset pricing performance of LR investment shocks. Section 7 concludes.

## 2 Related Research

This paper links two strands of literature. The first strand of literature argues that investment shocks are important drivers of business cycle fluctuations: Greenwood, Hercowitz, and Krussel (1997, 2000), Christiano and Fisher (2003), Fisher (2006), Jaimovich and Rebelo (2009), Justiniano, Primiceri, and Tambalotti (2010, 2011). Recently, a branch of this literature focuses on the co-movement puzzle generated by MEI shocks that represent the most popular way of modelling investment shocks: Khan and Tsoukalas (2011), Furlanetto and Seneca (2014a,b). A second strand of literature analyzes the asset pricing implications of investment shocks: Li (2014), Kogan and Papanikolaou (2014), Kogan, Papanikolaou, and Stoffman (2015), Garlappi and Song (2016b). Similarly to our paper, Papanikolaou (2011) and Segal (2015) analyze the joint implications of investment-specific shocks for macro quantities and asset prices.

Our two-sector model is similar to that of Jaimovich and Rebelo (2009), Papanikolaou (2011), and Segal (2015). We differ from Jaimovich and Rebelo (2009) with respect to two important aspects: the utility function and the structure of sectoral shocks. Jaimovich and Rebelo (2009) assume that the representative agent features habit formation in consumption and that the level of sectoral TFP is subject to permanent shocks which implies that the growth rate of sectoral TFP is a random walk. Differently, in our model the growth rate of sectoral TFP processes follows a random walk with time-varying drift.

Time variation in the drift induces long-run risk in consumption and investment. Therefore, we assume that the representative agent has Epstein-Zin preferences to ensure that sectoral long-run risk is priced in equilibrium.

We also differ from Papanikolaou (2011) with respect to investment-specific shocks: we consider LR shocks to the TFP process of the investment sector while Papanikolaou (2011) considers MEI shocks. Segal (2015) focuses on shocks to the conditional volatility of the investment sector TFP, while we analyze shocks to its conditional mean growth rate.

Solutions for the co-movement problem have been proposed in the literature recently. Khan and Tsoukalas (2011) show that the co-movement problem can be solved when the depreciation rate of capital is a convex function of its utilization or when the households' preferences are such that there is no wealth effect of labor.[2] Furlanetto and Seneca (2014a,b) solve the co-movement problem using a Calvo-style mechanism of price and wage rigidities, respectively. Similarly to Furlanetto and Seneca (2014a,b), we also use wage rigidities to induce the right co-movement between macroeconomic variables, but differently from them we use wage rigidities as proposed by Uhlig (2007).

More technically, the presence of the LR components in sectoral TFP processes creates long-run consumption and investment risk that are both priced in our economy because the representative agent has Epstein-Zin preferences. In our framework, the SR and LR components of sectoral TFP processes are exogenous quantities that drive the dynamics of all endogenous variables (consumption, output, investment, and labor). Kaltenbrunner and Lochstoer (2010) take a different perspective and analyze the conditions under which

[2] More precisely, Khan and Tsoukalas (2011) assume that the representative agent features habit formation in consumption as in Jaimovich and Rebelo (2009). They eliminate the wealth effect of labor by assuming that consumption habits depend on past consumption only, but not on current consumption.

long-run risk arises endogenously in a one-sector production economy with Epstein-Zin preferences. They show that the consumption-savings decisions of households endogenously produces long-run risk in consumption even when the (log of) TFP follows a random walk. Besides the main research question we also differ from Kaltenbrunner and Lochstoer (2010) with respect to the model characteristics. They consider a one-sector model where production depends on capital only. Differently, we build a two-sector model where production depends on both capital and labor. Thus, our equilibrium dynamics are also affected by the households' labor choice and by the interactions between the two sectors.

At the moment, there is no clear consensus in the literature concerning the implications of investment-specific shocks for the cross section of stock returns. Papanikolaou (2011) and Kogan and Papanikolaou (2013) find that investment-specific shocks are negatively priced in the cross section of stock returns. Differently, Li (2014) and Segal (2015) argue in favor of a positive market price of risk. Garlappi and Song (2016a) suggest potential measurement problems in the existing proxies of investment specific shocks that might contribute to these mixed results. With respect to this literature we show both theoretically and empirically that LR investment shocks command a positive risk premium and we use the different TFP components themselves in the empirical tests, instead of other proxy variables. In summary, we contribute to these strands of literature by showing that a new, previously disregarded source of investment-specific technical change, namely LR investment risk, has important implications for asset prices and macroeconomic fluctuations.

# 3 The Model

In the following subsections, we develop a dynamic stochastic general equilibrium (DSGE) model with two sectors that allows us to study the asset pricing implications of various shocks to investment good productivity and efficiency. The first sector is the consumption good sector. It admits a standard competitive representative firm that uses capital and labor to produce consumption goods which are supplied to the representative household for consumption. The second sector is the investment good sector that uses labor to produce investment goods which are then sold to the consumption good sector and used in the production of the consumption good. The representative household owns both sectors, has recursive preferences over consumption and leisure, and it freely allocates labor to the two sectors. The wage is subject to frictions in the form of sticky wages. The production technologies in both sectors are subject to both SR and LR productivity shocks. A summary of the equilibrium conditions and details about the solution of the model are provided in Appendix A.

## 3.1 Representative household

Because we want to focus on the trade-off between short-run and long-run shocks, we assume that the representative agent has recursive preferences of the Epstein and Zin (1989) type:

$$U_t = \left[ (1-\beta) v_t^{1-\frac{1}{\psi}} + \beta \left( \mathbb{E}_t \left[ U_{t+1}^{1-\gamma} \right] \right)^{\frac{1-1/\psi}{1-\gamma}} \right]^{\frac{1}{1-1/\psi}}, \tag{1}$$

where $\gamma$ denotes the relative risk aversion (RRA), $\psi$ measures the elasticity of intertemporal substitution (EIS), and $\beta \in (0,1)$ is the household's time discount factor. Note that this preference specification allows to separate the relative risk aversion from the elasticity of intertemporal substitution. The utility flow $v_t$ is a Cobb-Douglas index of aggregate consumption $C_t$ and leisure $\bar{L} - L_t$:

$$v_t := v(C_t, L_t) = C_t^{\nu} \left( A_{C,t}(\bar{L} - L_t) \right)^{1-\nu},$$

where $\nu \in (0, 1)$ reflects preferences for consumption versus leisure. $A_{C,t}$ (to be defined later) is the productivity of the consumption good sector and can be interpreted as the household's standard of living in the spirit of Croce (2014).[3] In each period, the representative household chooses consumption $C_t$ and labor $L_t$ to maximize (1) subject to the following budget constraint:

$$C_t + B_{t+1} + \vartheta_{C,t+1}(V_{C,t} - D_{C,t}) + \vartheta_{I,t+1}(V_{I,t} - D_{I,t}) = W_t^u L_t + B_t R_t^f + \vartheta_{C,t} V_{C,t} + \vartheta_{I,t} V_{I,t}, \quad (2)$$

where $\vartheta_{C,t}$ ($\vartheta_{I,t}$) denotes equity shares held from time $t-1$ to time $t$ in the representative firm producing the consumption (investment) good. $V_{C,t}$ ($V_{I,t}$) and $D_{C,t}$ ($D_{I,t}$) is the cum-dividend market value and the dividend of the firm producing the consumption (investment) good. $B_t$ denotes bond holdings from time $t-1$ to time $t$, $R_t^f$ is the gross risk-free rate, and $W_t^u$ represents the frictionless wage. Hence, the household chooses the amount of hours allocated to labor as if the wage was not sticky (wage rigidities are introduced later in Section 3.4). The first-order conditions of the maximization problem lead to the following expression for the stochastic discount factor (SDF):

$$\mathbb{M}_{t,t+1} = \beta \left( \frac{C_{t+1}}{C_t} \right)^{-1} \left( \frac{v_{t+1}}{v_t} \right)^{1-\frac{1}{\psi}} \left( \frac{U_{t+1}}{(\mathbb{E}_t[U_{t+1}^{1-\gamma}])^{\frac{1}{1-\gamma}}} \right)^{\frac{1}{\psi}-\gamma}. \quad (3)$$

[3] Multiplying leisure by productivity in the utility flow also guarantees balanced growth. Defining the utility flow alternatively as either $C_t(\bar{L} - L_t)^{\nu}$ or $C_t^{\nu}(A_{C,t-1}(\bar{L} - L_t))^{1-\nu}$ does not change the predictions of the model qualitatively, and the quantitative changes to the model-implied moments are relatively small. These results are available upon request.

The usual Euler equations of cum-dividend asset prices can be written as:

$$V_{C,t} = D_{C,t} + \mathbb{E}_t[\mathbb{M}_{t,t+1} V_{C,t+1}], \quad V_{I,t} = D_{I,t} + \mathbb{E}_t[\mathbb{M}_{t,t+1} V_{I,t+1}], \quad \frac{1}{R_t^f} = \mathbb{E}_t[\mathbb{M}_{t,t+1}].$$

Finally, the household's optimal labor allocation leads to the following condition:

$$W_t^u = \frac{1-\nu}{\nu} \frac{C_t}{\bar{L} - L_t}.$$

## 3.2 Consumption goods sector

The consumption goods sector admits a representative perfectly competitive firm utilizing capital and labor to produce the consumption goods. The production technology is given by:

$$Y_{C,t} = K_{C,t}^{\alpha_C} \left(A_{C,t} L_{C,t}\right)^{1-\alpha_C},$$

where $\alpha_C$ is the capital share, labor $L_{C,t}$ is supplied by the household, and $A_{C,t}$ is the exogenous labor-augmenting productivity. We assume that $A_{C,t}$ is subject to both short-run and long-run shocks:

$$A_{C,t} = e^{a_{C,t}}, \quad a_{C,t} = \mu_C + x_{C,t-1} + a_{C,t-1} + \sigma_C \varepsilon_{C,t}, \quad x_{C,t} = \rho_C x_{C,t-1} + \sigma_{x,C} \varepsilon_{x,C,t}.$$

The unconditional expected growth rate of productivity is $\mu_C$. Short-run productivity shocks are induced by $\varepsilon_{C,t}$, whereas $\varepsilon_{x,C,t}$ indicates long-run shocks which affect the stochastic component in expected productivity growth $x_{C,t}$. The persistence of long-run productivity shocks is measured by $\rho_C$. Moreover, capital $K_{C,t}$ accumulates according to:

$$K_{C,t+1} = (1-\delta_K)K_{C,t} + G\left(i_{C,t}\right)K_{C,t}. \tag{4}$$

Here, $i_{C,t} = \frac{I_{C,t}}{K_{C,t}}$, and $\delta_K$ is the depreciation rate of capital. The function $G$ captures adjustment costs of investments as in Jermann (1998):

$$G_t := G\left(i_{C,t}\right) = \frac{\alpha_1}{1-\frac{1}{\tau}}\left(i_{C,t}\right)^{1-\frac{1}{\tau}} + \alpha_2,$$

where the constants $\alpha_1$ and $\alpha_2$ are chosen such that there are no adjustment costs in the deterministic steady state.

The net profit of the consumption goods sector $D_{C,t}$ is given by output minus the expenditure on investment goods and wages:

$$D_{C,t} = Y_{C,t} - P_{I,t}I_{C,t} - W_t L_{C,t}. \tag{5}$$

The representative firm chooses labor, capital, and investment to maximize its value, i.e., the firm solves:

$$V_{C,0} = \max_{\{K_{C,t+1},I_{C,t},L_{C,t}\}_{t=0}^{t=\infty}} \sum_{t=0}^{\infty} \mathbb{E}_0\left[\mathbb{M}_{0,t}D_{C,t}\right], \tag{6}$$

subject to the capital accumulation constraint (4). The first-order condition with respect to $K_{C,t+1}$,

$$1 = \mathbb{E}_t\left[\mathbb{M}_{t,t+1}\frac{1}{\lambda_t}\left(\frac{\alpha_C Y_{C,t+1} - P_{I,t+1}I_{C,t+1}}{K_{C,t+1}} + \lambda_{t+1}(G_{t+1} + 1 - \delta_K)\right)\right], \tag{7}$$

determines the price of the investment good $P_{I,t}$. The Lagrange multiplier attached to the capital accumulation constraint $\lambda_t$ is pinned down by the first-order condition with respect to investment:

$$\lambda_t = \frac{P_{I,t}}{G'_t}, \tag{8}$$

where $G'_t$ is the derivative of $G_t$ with respect to the investment-to-capital ratio $i_{C,t}$. Finally, the first-order condition with respect to labor $L_{C,t}$ implies the following condition that determines the wage $W_t$:

$$W_t L_{C,t} = (1 - \alpha_C) Y_{C,t}. \tag{9}$$

### 3.3 Investment goods sector

The investment goods sector supplies investment goods to the consumption goods sector. It is populated by a representative firm that sells the demanded goods at the price $P_{I,t}$. Investment goods are produced according to the technology:

$$Y_{I,t} = A_{I,t} L_{I,t}^{1-\alpha_I},$$

where $L_{I,t}$ is labor supplied by the household, $1 - \alpha_I$ is the labor share, and $A_{I,t}$ is the stochastic total factor productivity of the investment goods sector, whose dynamics are given by the following process:

$$A_{I,t} = e^{a_{I,t}}, \quad a_{I,t} = \mu_I + x_{I,t-1} + a_{I,t-1} + \sigma_I \varepsilon_{I,t}, \quad x_{I,t} = \rho_I x_{I,t-1} + \sigma_{x,I} \varepsilon_{x,I,t}.$$

Thus, as in the consumption goods sector, the productivity of the investment goods sector is subject to both short-run ($\varepsilon_{I,t}$) and long-run ($\varepsilon_{x,I,t}$) shocks. The unconditional expected growth rate of investment goods sector's productivity is denoted by $\mu_I$, and $\rho_I$ denotes the persistence of long-run investment shocks. In Section 5.1 we provide empirical evidence for the presence of LR components in the TFP processes of the consumption and investment sector. The LR component in the productivity of investments also captures the idea of investment hysteresis originally proposed by Dixit (1992). Classic theory postulates that firms should invest (or enter the market) when the price exceeds the average variable costs and disinvest (or exit the market) when the price falls below the average variable costs. However, empirical evidence indicates that, once firms have invested in a project, they tend to stay in business and continue their investment even when the underlying causes of investment are fully reversed.[4] This suggests that investment drivers may have long-lasting effects that, in our model, are captured by time variation in $x_{I,t}$. The investment goods sector pays wages to the household and its total output $Y_{I,t}$ is sold to the consumption goods sector at the price $P_{I,t}$. The net profit of the investment goods sector is therefore given by:

$$D_{I,t} = P_{I,t}Y_{I,t} - W_t L_{I,t}. \tag{10}$$

The investment goods sector firm chooses labor $L_{I,t}$ to maximize the firm value:

$$V_{I,0} = \max_{\{L_{I,t}\}_{t=0}^{t=\infty}} \left\{ \sum_{t=0}^{\infty} \mathbb{E}_0 \left[ \mathbb{M}_{0,t} D_{I,t} \right] \right\}. \tag{11}$$

The first-order condition with respect to labor $L_{I,t}$ is given by:

$$W_t L_{I,t} = (1 - \alpha_I) P_{I,t} Y_{I,t}. \tag{12}$$

[4]The empirical evidence on investment hysteresis is still fragmented. A review of sectoral and experimental evidence on this topic can be found in Kogut and Chang (1996) and Bragger, Bragger, Hantula, and Kirnan (2003). A deep economic motivation for a delayed exit strategy is provided by Bernanke (1983). Further theoretical studies that point to the importance of long-term trends in investment dynamics are provided by Dixit (1989), Bar-Ilan and Strange (1996), Bar-Ilan and Strange (1999), and Kogan (2001).

### 3.4 Labor market frictions

We assume that the labor supply is subject to frictions. In the spirit of Blanchard and Galí (2007) and Uhlig (2007), we impose that a fraction of the labor supply does not reach the market. As shown by Uhlig (2007), this results in sticky wages, i.e., households' wages are given by:

$$W_t = \left( W_{t-1} \frac{A_{C,t-1}}{A_{C,t-2}} \right)^{\xi} (W_t^u)^{1-\xi},$$

where $W_t^u$ represents the frictionless wage. The intuition is that the household chooses labor hours as if there were no labor market frictions. Hence, $W_t^u$ appears in the household budget constraint (2). However, the actual salary paid to households is $W_t$, which therefore appears in the definition of firm's dividends (5), (10), and (14). The term $A_{C,t-1}/A_{C,t-2}$ captures the fact that the wage is indexed to aggregate productivity if it cannot be chosen optimally. The parameter $\xi$ controls the degree of wage rigidities. In particular, $\xi = 0$ implies the absence of labor market rigidities.

### 3.5 Market clearing conditions and aggregate dividends

The household supplies labor to the consumption and the investment goods sector. Thus, market clearing in the labor market dictates:

$$L_t = L_{C,t} + L_{I,t}.$$

Equating the supply and demand for investment goods implies:

$$I_{C,t} = Y_{I,t}. \tag{13}$$

The output of the consumption goods sector is fully consumed by the household and therefore the consumption good market clears when:

$$C_t = Y_{C,t} = W_t L_t + D_{M,t} = W_t L_t + D_{C,t} + D_{I,t}. \tag{14}$$

The second equality is obtained by assuming that $i$) bonds are in zero net supply and the stocks of the consumption and the investment goods sector firms are in unit net supply (i.e., $B_t \equiv 0$ and $\vartheta_{C,t} \equiv \vartheta_{I,t} \equiv 1$), and $ii$) households receive the actual wage $W_t$ in exchange for their labor supply and not the frictionless wage $W_t^u$. The aggregate ("market") dividends, $D_{M,t} = D_{C,t} + D_{I,t}$, are given by the sum of the dividends distributed by the consumption and the investment goods sector. The market value at time 0, which defines the aggregate equity premium in our economy, is consequently given by:

$$V_{M,0} = \sum_{t=0}^{\infty} \mathbb{E}_0 \left[ \mathbb{M}_{0,t} D_{M,t} \right].$$

## 3.6 Stochastic marginal efficiency of investment

Justiniano, Primiceri, and Tambalotti (2010) and Papanikolaou (2011) introduce a stochastic marginal efficiency of investment (MEI) in order to explain macroeconomic fluctuations and the main features of asset prices. To highlight the different implications of MEI shocks and LR investment shocks, we therefore also analyze an augmented economy with stochastic MEI. This comparison helps us to assess how our model with LR investment specific shocks performs relative to Justiniano, Primiceri, and Tambalotti (2010) and Papanikolaou (2011).

In the augmented economy, the marginal efficiency of investment goods is governed by the stochastic process $Z_{M,t}$. In order to increase the future capital stock by an absolute amount $G(i_{c,t})K_{C,t}$, the representative firm needs to buy $Z_{M,t}^{-1}I_{C,t}$ units of the investment good (and not $I_{C,t}$ as in our benchmark economy) at the relative price $P_{I,t}$. Therefore, the total investment cost is given by $Z_{M,t}^{-1}I_{C,t}P_{I,t}$. The log marginal efficiency of investment goods is stochastic and follows a strictly stationary AR(1) process:

$$\log(Z_{M,t}) = \rho_M \log(Z_{M,t-1}) + \sigma_M \varepsilon_{M,t}.$$

When the marginal efficiency of investment is stochastic some equations of our benchmark economy need to be changed. First, the net profit of the consumption goods sector $D_{C,t}$ is now given by:

$$D_{C,t} = Y_{C,t} - Z_{M,t}^{-1}P_{I,t}I_{C,t} - W_t L_{C,t}, \tag{15}$$

rather than by Equation (5). Correspondingly, the consumption goods firm's first-order condition with respect to capital (7) is replaced by:

$$1 = \mathbb{E}_t \left[ \mathbb{M}_{t,t+1} \frac{1}{\lambda_t} \left( \frac{\alpha_C Y_{C,t+1} - Z_{M,t+1}^{-1} P_{I,t+1} I_{C,t+1}}{K_{C,t+1}} + \lambda_{t+1}(G_{t+1} + 1 - \delta_K) \right) \right],$$

and the consumption goods firm's first-order condition with respect to investment, i.e., Equation (8), needs to be replaced by:

$$\lambda_t = \frac{Z_{M,t}^{-1} P_{I,t}}{G_t'}. \tag{16}$$

Finally, the market clearing condition of the investment market (13) becomes:

$$Z_{M,t}^{-1} I_{C,t} = Y_{I,t}.$$

# 4 Quantitative Analysis

We calibrate the model at quarterly frequency, consistent with the frequency of available data on sectoral output that we use to validate the empirical predictions of our model in Section 5. Our benchmark economy features SR and LR TFP shocks only, but no MEI shocks. We analyze the role of MEI shocks in the augmented economy in Section 4.4.

## 4.1 Calibration

Our calibration is summarized in Table 1. The preference parameters are set in accordance with the long-run risk literature. The subjective discount factor $\beta$ is set to 0.993 to help the model match the relatively low level of the risk-free rate observed in the data. We set the coefficients of relative risk aversion and elasticity of intertemporal substitution to values of 10 and 2, respectively. Similar values can be found in Bansal and Yaron (2004), Croce (2014), and Kung and Schmid (2015). Note that $\gamma > 1/\psi$, i.e. our representative agent has a preference for early resolution of uncertainty, which is also in line with the recent experimental evidence of Brown and Kim (2014). Following standard practice, the consumption share in the utility bundle $\nu$ is chosen such that the steady state supply of labor is one third of the total time endowment of the household. Given the other parameters, this is achieved by setting $\nu = 0.3514$.

The parameters of the sectoral TFP processes are selected to match as closely as possible the moments of asset prices and macroeconomic quantities as well as the empirical estimates of Section 5.1. $\mu_C$ and $\mu_I$ are such that the average annual growth rate of output is around 0.02, consistent with US data. We fix the persistence of sectoral LR components (i.e., $\rho_{C,t}$ and $\rho_{I,t}$) at 0.95 which corresponds to an annualized persistence of 0.80. This

**Table 1:** Quarterly benchmark calibration

| Parameter | Description | Source | Value |
|---|---|---|---|
| Preference parameters | | | |
| $\beta$ | Subjective discount factor | 4 | 0.993 |
| $\gamma$ | Risk aversion | 2 | 10 |
| $\psi$ | Elasticity of intertemporal substitution | 2 | 2 |
| $\nu$ | Consumption share in utility bundle | 4 | 0.3514 |
| Consumption goods sector | | | |
| Technology parameters | | | |
| $\alpha_C$ | Capital share in consumption good production | 1 | 0.3 |
| $\delta_K$ | Depreciation rate of physical capital | 1 | 0.02 |
| $\tau$ | Elasticity of adjustment costs in investment | 4 | 0.98 |
| TFP parameters | | | |
| $\mu_C$ | Long-run mean of consumption goods sector TFP | 2 | $0.018/4$ |
| $\sigma_C$ | Volatility of short-run shocks to consumption goods sector TFP $\varepsilon_C$ | 4 | $0.032/\sqrt{4}$ |
| $\rho_C$ | Autocorrelation of long-run shocks to consumption goods sector TFP $x_C$ | 4 | 0.95 |
| $\sigma_{x,C}$ | Volatility of long-run shocks to consumption goods sector TFP $\varepsilon_{x,C}$ | 4 | $0.1125 \cdot \sigma_C$ |
| Investment goods sector | | | |
| Technology parameters | | | |
| $\alpha_I$ | One minus the labor share in investment good production | 1 | 0.1 |
| TFP parameters | | | |
| $\mu_I$ | Long-run mean of investment goods sector TFP | 2 | $0.018/4$ |
| $\sigma_I$ | Volatility of short-run shocks to investment goods sector TFP $\varepsilon_I$ | 4 | $0.032/\sqrt{4}$ |
| $\rho_I$ | Autocorrelation of long-run shocks to investment goods sector TFP $x_I$ | 4 | 0.95 |
| $\sigma_{x,I}$ | Volatility of long-run shocks to investment goods sector TFP $\varepsilon_{x,I}$ | 4 | $0.1125 \cdot \sigma_I$ |
| Labor market | | | |
| $\xi$ | Wage rigidities parameter | 3 | 0.35 |

*Notes*: Parameters sources: 1=Papanikolaou (2011), 2=Croce (2014), 3=Uhlig (2007), 4=own calibration.

is also in line with Croce (2014). Our empirical estimates and the previous literature (Croce, 2014) suggest that the volatility of the LR shocks is a small percentage of the volatility of the SR shocks. Thus, we impose $\sigma_{x,C} = 0.1125 \cdot \sigma_C$ and $\sigma_{x,I} = 0.1125 \cdot \sigma_I$. Finally, we set $\sigma_C = \sigma_I = 0.032/\sqrt{4}$ to match the annualized volatility of output growth in the US for the period 1951–2008 (i.e., 3.24 percentage points).

The depreciation rate of physical capital in the consumption goods sector is standard and set to 0.02, similarly to Papanikolaou (2011). On the production side, also in line with Papanikolaou (2011), we set the capital share in consumption goods production $\alpha_C$ equal to 0.3. The labor share in investment goods production, i.e., $1 - \alpha_I$, is equal to 0.9.

The elasticity of the supply curve of capital $\tau$ is equal to 0.98, a value in line with existing empirical evidence.[5] Finally, following Uhlig (2007), we assume a moderate degree of wage stickiness by imposing $\xi = 0.35$ in the benchmark case. We also present robustness checks where we vary the parameter $\xi$. The model is solved in dynare++ 4.4.3 using a second-order approximation.

## 4.2 Macro quantities and asset prices

Table 2 reports key unconditional moments of macroeconomic and asset pricing quantities, obtained from model simulations. We consider several sub-cases that allow us to highlight the role played by sectoral SR and LR shocks. In column [1] we report the main features of an economy without long-run risk. Then, we introduce long-run risk in the consumption sector only (column [2]), and finally we allow for long-run risk in both the consumption and the investment sector (column [3]). In all of these cases, we assume the absence of wage rigidities.

In the absence of long-run risk the model has difficulties in matching the basic properties of stock returns, most importantly the equity premium. The model reproduces the positive co-movement between consumption and output, but fails on all the other macroeconomic co-movements.

Introducing long-run risk in the consumption sector (column [2]) makes this sector relatively riskier (as compared to the case of no long-run risk), which leads to a substantial increase in the risk premium required to hold the consumption sector equity. As a result, the market equity premium increases from 1.20 to 3.69 percentage points. However, long-run risk in the consumption sector produces even more counterfactual results for the

[5] Eberly (1997), for instance, reports estimates that range between 1.08 and 1.36. In an earlier empirical work, Abel (1980) reports values for $\tau$ between 0.5 and 1.14.

co-movement of consumption and investment and the co-movement of consumption and labor, as those numbers turn negative in column [2].

Introducing long-run risk in the investment sector (column [3]) further improves asset pricing quantities, especially the stock return volatility of the investment sector and the return differential between the two sectors. More precisely, the volatility spread between the investment and the consumption sector increases from 1.21 to 4.25 percentage points and gets closer to the value observed in the data (10.96 percentage points). Nevertheless, the risk premium of the consumption sector is higher than that of the investment sector. This can be explained by differences in the cyclical variation between the two sectors: due to adjustment costs, consumption is much more pro-cyclical than investments, i.e. $\text{corr}(\Delta c, \Delta y) > \text{corr}(\Delta i, \Delta y)$. Therefore, the consumption sector equity exhibits more systematic risk and earns a higher risk premium in equilibrium. The correlations among macroeconomic variables remain basically unaffected, in particular the correlation between consumption and investment and the correlation between consumption and labor remain slightly negative. This means that LR investment risk improves the model's ability to fit sectoral stock returns but to explain the unconditional correlations among macroeconomic variable we need an additional ingredient, namely wage rigidities.

Columns [4], [5], and [6] report results for the economy with long-run risk in both sectors and progressively higher degrees of wage rigidities, where column [5] refers to our benchmark economy with $\xi = 0.35$. The introduction of wage rigidities solves the co-movement problem and the unconditional correlations between consumption and investment and between consumption and labor switch sign and turn positive. Wage rigidities also have implications for asset prices. They prevent wages from perfectly adjusting to TFP changes and thus impair the ability of firms to react to macroeconomic shocks. As a result, firms' equity becomes riskier. The equity volatility increases and households require a higher risk premium to hold stocks in equilibrium.

**Table 2:** Model versus Data: Macroeconomic Quantities and Asset Prices

| | | The Role of LRR | | | The Role of Wage Rigidities | | |
|---|---|---|---|---|---|---|---|
| Model | Data | [1] | [2] | [3] | [4] | **[5]** | [6] |
| **ASSET PRICES** | | | | | | | |
| $\mathbb{E}[R_M - R_f]$ | 4.89 | 1.20 | 3.69 | 3.68 | 3.75 | **3.97** | 4.18 |
| $\sigma[R_M - R_f]$ | 17.92 | 4.05 | 5.75 | 5.73 | 5.87 | **6.40** | 6.61 |
| $\mathbb{E}[R_f]$ | 2.90 | 3.21 | 2.38 | 2.38 | 2.34 | **2.20** | 2.08 |
| $\sigma[R_f]$ | 3.00 | 0.09 | 0.41 | 0.41 | 0.53 | **1.50** | 2.35 |
| $\mathbb{E}[R_I - R_C]$ | -1.41 | -1.44 | -1.71 | -1.44 | -1.45 | **-1.44** | -1.45 |
| $\sigma[R_I] - \sigma[R_C]$ | 10.96 | 0.82 | 1.21 | 4.25 | 4.14 | **3.64** | 3.16 |
| **MACRO QUANTITIES** | | | | | | | |
| $\sigma(\Delta y)$ | 3.24 | 2.30 | 2.43 | 2.46 | 2.60 | **3.24** | 3.97 |
| $\sigma(\Delta y)/\sigma(\Delta c)$ | 1.66 | 1.01 | 1.01 | 1.01 | 1.00 | **1.01** | 1.01 |
| $\sigma(\Delta i)/\sigma(\Delta y)$ | 1.92 | 1.33 | 1.50 | 1.55 | 1.50 | **1.33** | 1.26 |
| $\sigma(\Delta l)/\sigma(\Delta y)$ | 0.78 | 0.02 | 0.15 | 0.15 | 0.24 | **0.65** | 0.86 |
| $\sigma(\Delta l)$ | 2.52 | 0.05 | 0.37 | 0.38 | 0.62 | **2.12** | 3.42 |
| $\rho(\Delta c, \Delta y)$ | 0.84 | 0.99 | 0.98 | 0.98 | 0.98 | **0.99** | 0.99 |
| $\rho(\Delta c, \Delta i)$ | 0.39 | 0.06 | -0.01 | -0.01 | 0.04 | **0.30** | 0.50 |
| $\rho(\Delta c, \Delta l)$ | 0.41 | 0.61 | -0.03 | -0.05 | 0.30 | **0.67** | 0.80 |
| $\rho(\Delta i, \Delta l)$ | 0.83 | -0.39 | 0.48 | 0.45 | 0.38 | **0.53** | 0.68 |
| $\rho(\Delta i, \Delta y)$ | 0.67 | 0.05 | 0.08 | 0.07 | 0.12 | **0.36** | 0.55 |

*Notes*: This table reports the main annual moments for the benchmark calibration ([5]) and five other model specifications. Means and volatilities are reported in percentage points. Model 1: No LRR in either sector (i.e., $\sigma_{x,C} = \sigma_{x,I} = 0$) and no wage rigidities (i.e., $\xi = 0$). Model 2: LRR in the consumption sector only (i.e., $\sigma_{x,C} > 0$, $\sigma_{x,I} = 0$) and no wage rigidities (i.e., $\xi = 0$). Model 3: LRR in both sectors (i.e., $\sigma_{x,C} > 0$, $\sigma_{x,I} > 0$) and no wage rigidities (i.e., $\xi = 0$). Models 4, 5, and 6: LRR in both sectors (i.e., $\sigma_{x,C} > 0$, $\sigma_{x,I} > 0$) and different degrees of wage rigidities ($\xi = 0.1$, $\xi = 0.35$, and $\xi = 0.5$, respectively). The entries for the models are obtained by repetitions of small-sample simulations. All empirical moments are from Papanikolaou (2011) for the time period 1951–2008.

Overall, our model is able to produce realistic moments for both macroeconomic and asset pricing quantities. Our benchmark calibration produces an equity premium of 3.97 percentage points and a low and stable risk-free rate (2.20 percentage points with a volatility of 1.50 percentage points). The model also succeeds in generating the average return spread between the investment and consumption sector (-1.44 percentage points vs. -1.41 percentage points in the data). Admittedly, like most DSGE models, our models encounters some difficulties in generating high stock return volatilities. Nevertheless, our model generates the right sign for the volatility spread between the investment and consumption sector equity, and this spread is much larger than in any of the cases without LR investment shocks (see also Table 3 below).[6] The standard deviation of output growth is exactly as in US macroeconomic data. In addition, the relative standard deviations of consumption, investment, and labor to output are not far from their empirical counterparts. Finally, the model-implied correlations among macroeconomic variables are positive, ranging from 0.30 to 0.99, and are all close to the values in the data.

### 4.3 Impulse response analysis

Figure 1 depicts the theoretical impulse response functions.[7] Our model features four types of shocks, and the four shocks contribute to the macroeconomic co-movement in different ways.

It is instructive to start looking at the two investment-specific shocks. After a positive SR investment shock, the investment sector becomes relatively more profitable *immedi-*

[6] The very recent asset pricing literature shows promising new economic channels which enable DSGE models to produce reasonable levels of return volatility. For instance, Nezafat and Slavík (2015) develop a rich model that generates a sizeable stock market volatility through financial shocks affecting the tightness of firms' financing constraints. Croce (2014) obtains a volatility of about 11 percentage points by assuming a high persistence of long-run productivity shocks (0.95 annually). Favilukis and Lin (2016) obtain values of similar magnitude with stochastic firm leverage and labor rigidities in the form of infrequent renegotiation of wages. The model of Papanikolaou (2011) generates high values of the stock market volatility when the volatility of shocks to the marginal efficiency of investments is set to 13.5 percentage points or the volatility of investment productivity shocks is set to 20 percentage points, but the volatility spread between the investment and consumption sectors is very similar to what we report in Table 2.

[7] The impulse response functions are computed in dynare++ 4.4.3 by perturbing the equilibrium system around the steady state. An alternative way to study the theoretical responses of equilibrium variables is to compute population impulse response functions (Carlstrom, Fuerst, and Paustian (2009) and Hussain and Liu (2016)) obtained by applying a VAR on model generated data. As the results from both approaches are similar, we discuss the impulse-response functions from perturbation here only. The results for the simulated VAR obtained from a long sample of model generated data are reported in Appendix B. Since we have long-run consumption and investment shocks in our model, using a number of short samples of model generated data (equal to the length of the empirical data) to estimate the VAR can be problematic (see, for instance, Colacito and Croce, 2011). Therefore, we do not follow this approach.

*ately.* Households, thus, find it optimal to increase investment immediately. Consumption also increases slightly in the period of the shock, and it continues to fluctuate until period 5, whereas investment reverts to the steady state already in period 2. This diverging behavior of consumption and investment after period 1 in response to SR investment shocks causes negative conditional co-movement. To ensure that the consumption stream remains smooth over time, households decrease labor today and then gradually readjust their labor supply toward the steady state. SR investment shocks also have a negative initial impact on total output $Y_t = C_t + P_{I,t} I_{C,t}$. Given that consumption and investment both increase initially after the shock, the drop in output is fully explained by the decline in the price of investment goods.

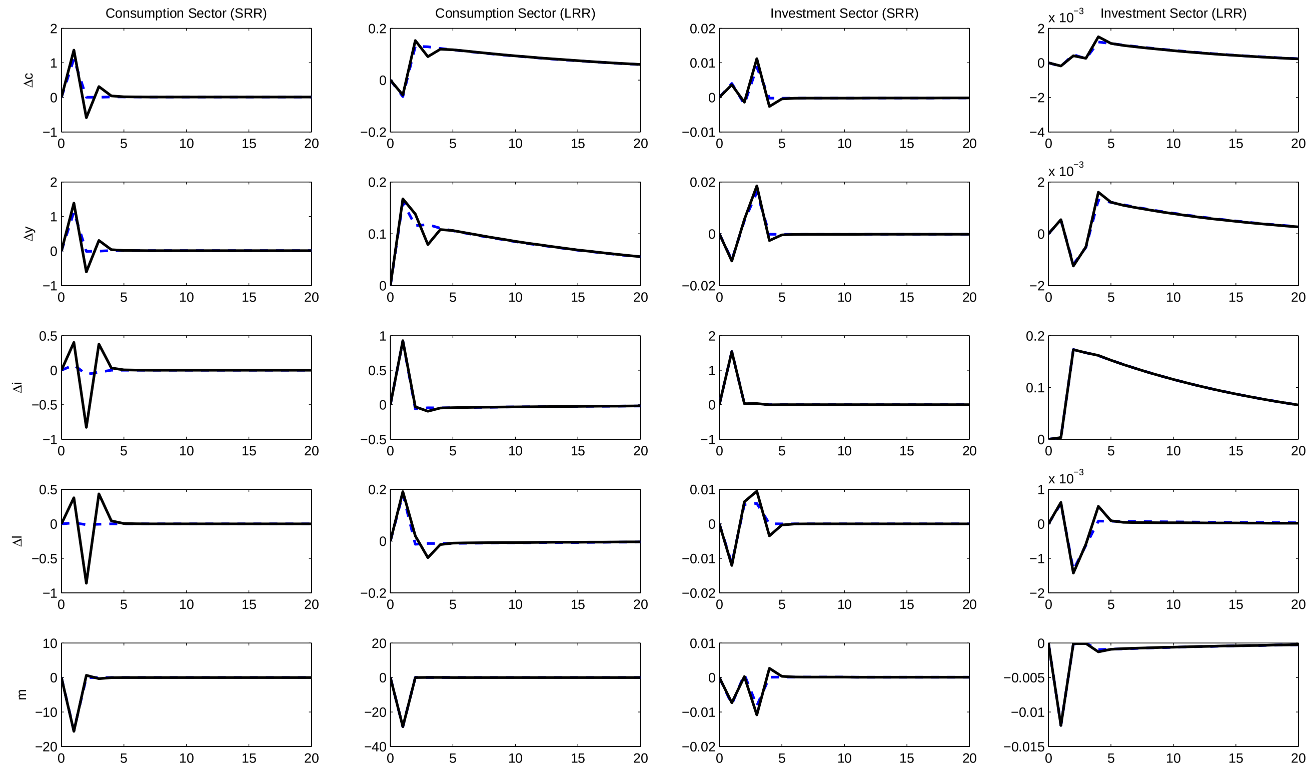
After a positive LR investment shock, the expected *future* profitability of the investment sector increases and households decide to invest more today and in the following periods. At the same time, households perceive themselves to be richer and want to increase current consumption. However, contrary to the reaction to short-run shocks, since the positive effect of LR investment shocks will materialize only over time, households have to finance their desired level of consumption by working more today. This increase in labor supply stimulates the total output of the economy.

In summary, SR and LR investment shocks have different implications for the co-movement of macroeconomic quantities. SR investment shocks affect the current profitability of the investment sector and generate a substitution effect that is the source of the negative co-movement among macroeconomic variables. Differently, LR investment shocks affect the future profitability of the investment sector and generate a positive wealth effect that induces positive co-movement among macroeconomic variables.

The other two sources of variation have been studied extensively in the literature, and our results basically replicate the ones by Croce (2014). After a positive shock to the SR component of consumption TFP, households find it optimal to increase consumption, investment, and labor simultaneously. As a result, total output also increases. Short-run consumption TFP shocks thus induce positive macroeconomic co-movement. The responses to LR shocks are slightly different and depend on the relation between the substitution effect and the wealth effect, which itself depends mainly on the IES. After a positive shock to the long-run consumption TFP, the continuation value of utility increases. In our parametrization, the IES is larger than one. Therefore, the substitution effect dominates the wealth effect, current consumption and continuation utility are substitutes, and households find it optimal to decrease consumption today and invest instead. However, consumption growth decreases only by a small amount and increases again after one quarter.

The unconditional correlations among macroeconomic quantities result from the interaction of all four types of shocks described above. Since the positive co-movement induced by SR consumption shocks and LR investment shocks is quantitatively smaller than the negative co-movement induced by the other shocks (SR investment shocks and LR consumption shocks), the unconditional correlations between consumption and investment and between consumption and labor remain slightly negative unless we introduce wage rigidities. So, how do wage rigidities help reproducing the positive correlation between consumption and investment and between consumption and labor? As one can see from Figure 1, where the solid lines refer to the case with wage rigidities and the dotted lines to the case without them, the main effect comes from SR consumption TFP shocks. After such a shock, firms find it optimal to increase their labor demand. When the labor market is fully flexible this leads to an increase in wages that almost completely offsets the incentive of firms to hire more workers. With wage rigidities, firms face an increase in the labor demand and a relatively smaller increase in salary, which increases the desire of firms to hire more workers. As a result, in the economy with wage rigidities the positive responses of labor, investment, and consumption with respect to SR shocks to the TFP process of the consumption sector are amplified as compared to an economy with fully flexible wages. In other words, with wage rigidities the negative co-movement between macroeconomic variables induced by SR shocks to the TFP of the investment sector is overcompensated by the positive co-movement resulting from SR shocks to the TFP of the consumption sector, and the overall correlation among key macroeconomic variables turns positive.

**Figure 1:** Impulse response functions




*Notes*: This figure depicts the impulse-response functions for a length of 20 quarters of log consumption growth $\Delta c$, log output growth $\Delta y$, log investment growth $\Delta i$, log labor growth $\Delta l$, and log stochastic discount factor $m$. Impulse-response functions with respect to i) a positive one-standard deviation SR shock to the consumption sector TFP ($\epsilon_C$), ii) a positive one-standard-deviation LR shock to consumption sector TFP ($\epsilon_{x,C}$), iii) a positive one-standard deviation SR shock to investment sector TFP ($\epsilon_I$) and iv) a positive one-standard-deviation LR shock to investment sector TFP (i.e., $\epsilon_{x,I}$) are depicted in columns 1, 2, 3, and 4, respectively. The solid black line refers to the case with wage rigidities ($\xi = 0.35$) while the dotted blue line refers to the case with the absence of wage rigidities ($\xi = 0$). The values reported are deviations from the steady state in percentage points.

## 4.4 Stochastic marginal efficiency of investment

We argue that shocks to the TFP process of the investment sector are an alternative way to capture time variation in real investment opportunities. Thus, at this point it is instructive to compare the implications of SR and LR investment shocks with those of more established MEI shocks. In this section, we analyze an augmented economy that features MEI shocks in addition to SR and LR shocks to the TFP processes of consumption and investment sectors. The parameters related to the marginal efficiency of investment are calibrated following the recent literature. We fix $\sigma_M$ to an annualized value of 0.12 which is within the confidence intervals estimated by Justiniano, Primiceri, and Tambalotti (2010). Moreover, we assume that the persistence of MEI shocks equals the persistence of the LR components of the sectoral TFP processes and therefore set $\rho_M = 0.95$, similarly to Furlanetto and Seneca (2014b).

In Table 3, we compare our benchmark economy that features only SR and LR shocks in the sectoral TFP processes (column [1]) with an economy that features also MEI shocks in addition to sectoral SR and LR shocks (column [2]). MEI shocks decrease the correlation among key macroeconomic variables: the correlation between consumption and investment decreases from 0.30 to 0.10 (vs. 0.39 in the data), the correlation between investment and labor decreases from 0.53 to 0.16 (vs. 0.83 in the data) and the correlation between investment and output decreases from 0.36 to 0.10 (vs. 0.67 in the data). The reasons for these results are illustrated in Figure 2 which depicts the impulse responses to MEI shocks. One can see that MEI shocks induce a negative co-movement between consumption, output, and labor. Actually, the impulse responses are similar to the impulse responses to short-run investment shocks depicted in Figure 1. This result suggests that MEI shocks and SR investment shocks have similar implications for the co-movement among macroeconomic quantities: both positive MEI shocks and positive SR investment shocks increase the current profitability of investments and create a negative substitution effect that induces households to work less and invest more.

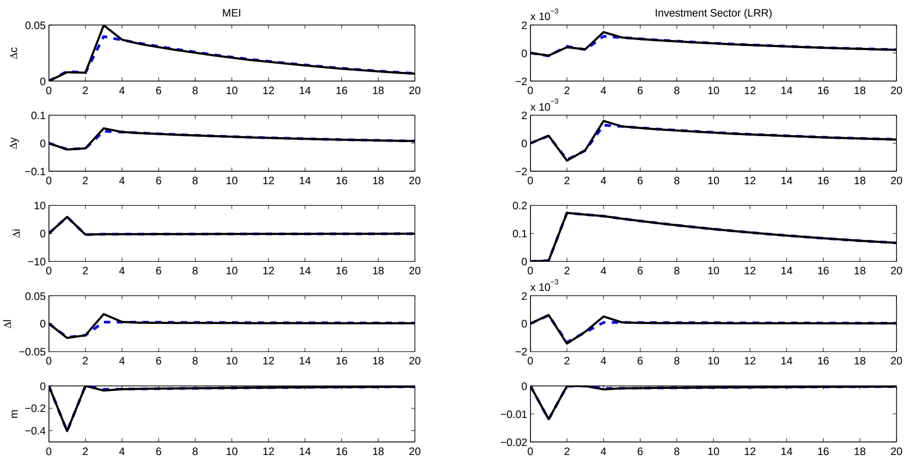
**Table 3:** INCLUSION OF MEI SHOCKS: MODEL VERSUS DATA

| | | The Role of MEI | | | | | |
|---|---|---|---|---|---|---|---|
| Model | DATA | [1] | [2] | [3] | [4] | [5] | [6] |
| **ASSET PRICES** | | | | | | | |
| $\mathbb{E}[R_M - R_f]$ | 4.89 | **3.97** | 3.98 | 3.67 | 3.98 | 1.48 | 4.38 |
| $\sigma[R_M - R_f]$ | 17.92 | **6.40** | 6.45 | 5.76 | 6.47 | 4.85 | 7.48 |
| $\mathbb{E}[R_f]$ | 2.90 | **2.20** | 2.20 | 2.38 | 2.20 | 3.04 | 1.96 |
| $\sigma[R_f]$ | 3.00 | **1.47** | 1.50 | 0.42 | 1.47 | 1.41 | 3.08 |
| $\mathbb{E}[R_I - R_C]$ | -1.41 | **-1.44** | -1.45 | -1.45 | -1.71 | -1.44 | -1.72 |
| $\sigma[R_I] - \sigma[R_C]$ | 10.96 | **3.64** | 3.70 | 4.34 | 0.63 | 0.27 | 0.05 |
| **MACRO QUANTITIES** | | | | | | | |
| $\sigma(\Delta y)$ | 3.24 | **3.24** | 3.28 | 2.47 | 3.21 | 3.07 | 4.59 |
| $\sigma(\Delta y)/\sigma(\Delta c)$ | 1.66 | **1.01** | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| $\sigma(\Delta i)/\sigma(\Delta y)$ | 1.92 | **1.33** | 3.84 | 5.03 | 3.91 | 4.08 | 2.86 |
| $\sigma(\Delta l)/\sigma(\Delta y)$ | 0.78 | **0.65** | 0.66 | 0.15 | 0.65 | 0.67 | 0.98 |
| $\sigma(\Delta l)$ | 2.52 | **2.17** | 2.17 | 0.37 | 2.09 | 2.06 | 4.48 |
| $\rho(\Delta c, \Delta y)$ | 0.84 | **0.99** | 0.99 | 0.98 | 0.99 | 0.99 | 0.99 |
| $\rho(\Delta c, \Delta i)$ | 0.39 | **0.30** | 0.10 | -0.02 | 0.11 | 0.12 | 0.28 |
| $\rho(\Delta c, \Delta l)$ | 0.41 | **0.67** | 0.68 | -0.02 | 0.66 | 0.73 | 0.86 |
| $\rho(\Delta i, \Delta l)$ | 0.83 | **0.53** | 0.16 | 0.02 | 0.16 | 0.12 | 0.32 |
| $\rho(\Delta i, \Delta y)$ | 0.67 | **0.36** | 0.10 | -0.01 | 0.11 | 0.10 | 0.28 |

*Notes*: This table reports the main moments for the benchmark calibration ([1]) and five other model specifications featuring shocks to the marginal efficiency of investment (MEI). Means and volatilities are reported in percentage points. Model 1: Benchmark calibration. Model 2: Benchmark + MEI shocks (i.e., $\sigma_M = 0.12/\sqrt{4}$). Model 3: Benchmark + MEI shocks and no wage rigidities (i.e., $\sigma_M = 0.12/\sqrt{4}$, $\xi = 0$). Model 4: Benchmark + MEI shocks, no LRR in the investment sector, and wage rigidities (i.e., $\sigma_M = 0.12/\sqrt{4}$, $\sigma_{x,I} = 0$, $\xi = 0.35$) Model 5: MEI shocks, no LRR risk in both sectors (i.e., $\sigma_M = 0.12/\sqrt{4}$, $\sigma_{x,c} = \sigma_{x,I} = 0$, $\xi = 0.35$). Model 6: Benchmark + MEI shocks, no LRR in the investment sector, and a large degree of wage rigidities (i.e., $\sigma_M = 0.12/\sqrt{4}$, $\sigma_{x,I} = 0$, $\xi = 0.60$) The entries for the models are obtained by repetitions of small sample simulations. All empirical moments are from Papanikolaou (2011) for the time period 1951–2008.

As a result, when we remove wage rigidities (column [3]) the unconditional correlations between consumption and investment, consumption and labor, and investment and output become negative. Note that the effect previously described is not present in a model based on LR investment shocks. In fact, Table 2 reveals that the introduction of LR investment risk in an otherwise comparable model improves the model's ability to fit asset prices but does not affect unconditional correlations among macroeconomic quantities. For this reason, in the presence of LR investment shocks, we only need a moderate degree of rigidities to obtain sizable correlations among macroeconomic quantities. Differently, in the presence of MEI shocks the moderate degree of wage rigidities that generates sizable unconditional correlations in our benchmark calibration (column [1]) generates significantly lower correlations between consumption and investment and between investment and output (see columns [2], [4], and [5]).

**Figure 2:** Impulse Response Functions for Marginal Efficiency of Investment Shocks




*Notes*: This figure depicts the impulse-response functions for a length of 20 quarters of log consumption growth $\Delta c$, log output growth $\Delta y$, log investment growth $\Delta i$, log labor growth $\Delta l$, and log stochastic discount factor $m$. Left column: Impulse response functions with respect to a positive one-standard-deviation shock to the marginal efficiency of investment (i.e., $\epsilon_M$). Right column: Impulse-response functions with respect to a positive one-standard-deviation shock to the LR component of the investment TFP process (i.e., $\epsilon_{x,I}$). IRFs are reported for two different degrees of wage rigidities: $\xi = 0$ (dotted blue lines) and $\xi = 0.35$ (solid black lines). The values reported are deviations from the steady state in percentage points. The parameters for MEI shocks are given by $\rho_M = 0.95$ and $\sigma_M = 0.12/\sqrt{4}$. All the other parameters are calibrated as in Table 1.

To match the correlation between consumption and investment in the presence of MEI shocks one has to increase the degree of wage rigidities. Wage rigidities impair the ability of the two sectors to react to macroeconomic shocks and thus increase the volatility of sectoral cash flows. Since the output of the investment sector is the input of the consumption sector, wage rigidities have a double effect on the volatility of the consumption sector returns which, as a result, increases more than the volatility of the investment sector returns when wage rigidities increase. The final result of this mechanism is that the return volatility differential between the investment and the consumption sector decreases when wage rigidities increase. This is evident in column [6] where we increase wage rigidities to obtain a high correlation between consumption and investment (0.28 vs. 0.39 in the data) and the return volatility differential decreases to 0.05 percentage points.

# 5 Empirical Evidence on the Mechanism

Having discussed the theoretical properties of the model, we now provide empirical evidence on the mechanism highlighted by our model. We obtain empirical measures of SR and LR components of sectoral TFP processes from US sectoral TFP data. Next, we estimate a vector auto-regressive VAR(1) model that includes key macroeconomic variables and our empirical measures of SR and LR components of sectoral TFP processes. Finally, we compare the empirical impulse response functions with those from our equilibrium model and provide forecast error variance decompositions for the empirical VAR(1) model.

## 5.1 Estimating SR and LR sectoral TFP processes

To test the predictions of our model we first need to extract LR components of sectoral TFP processes. As in Segal (2015), we use the sectoral TFP data originally suggested by Fernald (2012) and currently available from the Federal Reserve Bank of San Francisco.[8] These data are computed as the Solow residual of different sectors and decom-

[8] Further details on the data are given in Appendix C. The advantage of Fernald's data, compared to other datasets on sectoral TFP processes, is that they are available at quarterly frequency. For instance,

posed into utilization-adjusted series for equipment investment and consumption.[9] Data are quarterly and cover the time period 1947:Q2–2016:Q1. We estimate the SR and LR components using the standard state space approach:[10]

$$\Delta TFP_{C,t} = 0.0084 + x_{C,t-1} + \underbrace{\sigma^{sr}_{C,t}}_{0.0337^{***}[0.000]} \cdot \varepsilon_{1,t}$$

$$x_{C,t} = 0.9 \cdot x_{C,t-1} + \underbrace{\sigma^{lr}_{C,t}}_{0.0040^{***}[0.000]} \cdot \varepsilon_{2,t}$$

$$\Delta TFP_{I,t} = 0.0264 + x_{I,t-1} + \underbrace{\sigma^{sr}_{I,t}}_{0.0376^{***}[0.000]} \cdot \varepsilon_{3,t}$$

$$x_{I,t} = 0.9 \cdot x_{I,t-1} + \underbrace{\sigma^{lr}_{I,t}}_{0.0061^{***}[0.000]} \cdot \varepsilon_{4,t},$$

where $\sigma^{sr}_{C,t}$, $\sigma^{lr}_{C,t}$, $\sigma^{sr}_{I,t}$, and $\sigma^{lr}_{I,t}$ are the estimated volatilities of SR and LR consumption and investment TFP shocks, and the $\varepsilon_{j,t}$ $(j = 1, 2, 3, 4)$ are independent and identically distributed standard normal shocks. All parameter estimates are significant and the LR components of sectoral TFP processes are much less volatile than the SR components. The estimation provides us with four time series: SR and LR components of the consumption TFP process ($\Delta TFP_C$ and $x_C$) and SR and LR components of the investment TFP process ($\Delta TFP_I$ and $x_I$).

The EU KLEMS database (O'Mahony and Timmer, 2009) also contains sectoral TFP data but they are only available at annual frequency. The length of the time series is crucial for our analysis. In fact, as pointed out by Colacito and Croce (2011), the identification of LR components requires times series that are as long as possible.

[9]The definition of investment also includes durable consumption. Consumption is defined as business output less equipment investment and durable consumption.

[10]We use the Newton-Raphson optimization procedure with Marquardt step. In order to account for heteroskedasticity, we employ Huber-White standard errors.

## 5.2 Empirical impulse response functions

We compute Cholesky orthogonalized impulse response functions from a VAR(1) model that includes the LR component of the investment sector, the LR component of the consumption sector, the SR component of the investment sector, the SR component of the consumption sector, consumption growth, output growth, investment growth, and labor growth, in this order. Precisely, we estimate:

$$Z_t = C + AZ_{t-1} + \nu_t, \quad \mathbb{E}(\nu_t \nu_t') = V,$$

where $C$ is a vector of constants, and $V$ is the variance-covariance matrix of innovations $\nu_t$. The vector of variables $Z_t$ is given by:

$$Z_t = [x_{I,t}, x_{C,t}, \Delta TFP_{I,t}, \Delta TFP_{C,t}, \Delta c_t, \Delta y_t, \Delta i_t, \Delta l_t].$$

The order of variables reflects the economic mechanism behind our model where LR components of sectoral TFP are the most exogenous variables of our equilibrium model and determine the dynamics of sectoral TFP processes. Then, sectoral TFP and their LR components together drive the dynamics of all endogenous macroeconomic variables.[11] Data on macroeconomic aggregates are from the Bureau of Economic Analysis for the period 1947:Q2–2016:Q1.

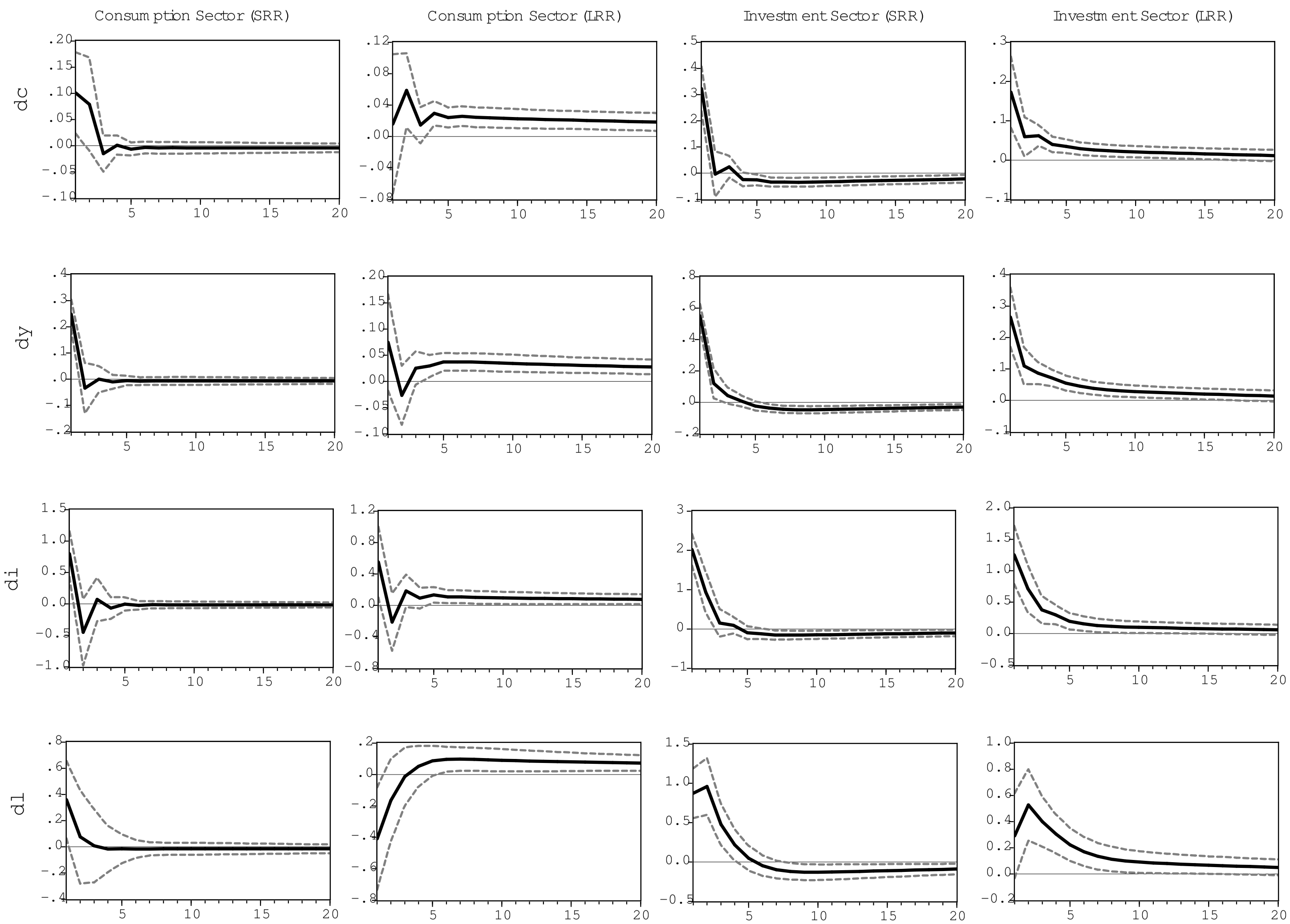
The impulse responses to SR and LR sectoral productivity shocks are depicted in Figure 3. In general, the impulse responses confirm that our model does not only quan-

[11] The Cholesky decomposition is frequently used in the literature to identify long-run type shocks. Segal, Shaliastovich, and Yaron (2015) use it to identify shocks to the volatility of consumption growth and to the volatility of the LR component of consumption growth. Similarly, Segal (2015) uses a Cholesky decomposition to identify shocks to the volatility of sectoral TFP processes. In both papers volatility processes are the most exogenous variables and, consistently, they are ordered first.

titatively match the macroeconomic and asset pricing moments, but that the mechanism through which the model operates exists in the data. Concerning investment-specific shocks, the positive co-movement resulting from LR investment shocks is largely confirmed by the empirical impulse responses. Consumption, investment, labor, and output all increase in response to such a shock, both in the model and in the data. We view this as evidence for our newly proposed channel of LR investment TFP shocks. Our model also predicts that consumption and investment increase after SR investment shocks while output and labor decline initially before turning positive after one quarter. The data display similar dynamics for consumption and investment. The initial negative response of labor and output in the model is the source of the co-movement puzzle. Therefore, it is not observed in the data. After the first quarter, however, the impact of SR investment shocks is positive, both in the model and in the data.

Even if we are mainly concerned with the implications of investment-specific shocks, to judge the empirical plausibility of our model we also need to analyze the empirical impulse responses to consumption-specific shocks. Concerning SR consumption shocks, our model predicts that macroeconomic quantities react positively to these shocks, and this is consistent with what we observe in the data. Moreover, a positive shock to the LR component of the consumption sector TFP process raises output and investment, both in the model and in the data. In the model consumption declines slightly right after the LR shock but then increases steadily over time. In the data consumption displays a positive response at all horizons, but the immediate response is not significant.

**Figure 3:** Empirical impulse responses to short-run and long-run sectoral productivity shocks (VAR8).




*Notes*: This figure depicts Cholesky orthogonalized impulse responses of consumption growth, output growth, investment growth, and labor growth to one-standard-deviation consumption TFP short-run and long-run and investment TFP short-run and long-run shocks. The gray dashed lines and the dotted black lines represent 95% confidence bands and point estimates, respectively. The horizontal axis represents quarters. The data are quarterly and run from 1947:Q2 to 2016:Q1. The VAR estimation includes a constant.

Overall, the empirical results support our claim that LR investment risk contributes positively to the co-movement among macroeconomic variables. To alleviate concerns that these results depend on the ordering of variables, as a robustness test we also estimate the generalized impulse response functions which are reported in Appendix B. The results are qualitatively and quantitatively very similar, and even more significant than those based on the Cholesky decomposition.

## 5.3 Variance decomposition

To quantify the relative importance of SR and LR sectoral shocks to macroeconomic fluctuations we report the variance decomposition of consumption, output, investment, and labor in Table 4. We observe that SR and LR components of sectoral TFP account for a relevant fraction of short-run and long-run fluctuations in key macro variables and their importance depends on both the forecasting horizon and the nature of the shock.

**Table 4:** FORECAST ERROR VARIANCE DECOMPOSITION OF MACRO VARIABLES DUE TO SHORT-RUN AND LONG-RUN SECTORAL TFP SHOCKS

| Period | Consumption | | | | Output | | | | Investment | | | | Labor | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $Q$ | $\Delta TFP_I$ | $X_I$ | $\Delta TFP_C$ | $X_C$ | $\Delta TFP_I$ | $X_I$ | $\Delta TFP_C$ | $X_C$ | $\Delta TFP_I$ | $X_I$ | $\Delta TFP_C$ | $X_C$ | $\Delta TFP_I$ | $X_I$ | $\Delta TFP_C$ | $X_C$ |
| *1* | 19.05 | 5.47 | 1.87 | 0.05 | 48.81 | 11.33 | 9.94 | 0.90 | 27.48 | 10.59 | 4.26 | 2.05 | 10.95 | 1.22 | 1.87 | 2.40 |
| | [4.12] | [2.76] | [1.43] | [0.53] | [4.30] | [3.65] | [2.18] | [1.14] | [4.33] | [3.54] | [1.88] | [1.66] | [3.49] | [1.41] | [1.54] | [1.91] |
| *4* | 17.53 | 6.46 | 2.78 | 0.80 | 42.90 | 12.73 | 8.45 | 1.04 | 22.28 | 10.32 | 3.77 | 1.75 | 16.48 | 5.17 | 1.14 | 1.66 |
| | [3.82] | [2.56] | [1.61] | [0.69] | [4.22] | [3.40] | [1.92] | [0.95] | [3.68] | [2.92] | [1.69] | [1.18] | [4.42] | [2.47] | [1.23] | [1.45] |
| *8* | 17.71 | 6.80 | 2.72 | 1.17 | 41.87 | 13.19 | 8.12 | 1.70 | 22.19 | 10.54 | 3.71 | 1.95 | 16.27 | 5.94 | 1.12 | 1.90 |
| | [3.75] | [2.47] | [1.57] | [0.69] | [4.17] | [3.21] | [1.86] | [0.87] | [3.64] | [2.88] | [1.66] | [1.16] | [4.35] | [2.52] | [1.21] | [1.46] |
| *16* | 18.11 | 6.95 | 2.63 | 1.69 | 40.93 | 12.93 | 7.65 | 2.62 | 22.33 | 10.57 | 3.63 | 2.18 | 16.65 | 6.14 | 1.10 | 2.30 |
| | [3.69] | [2.35] | [2.57] | [0.75] | [4.13] | [2.94] | [1.78] | [0.91] | [3.62] | [2.78] | [1.62] | [1.14] | [4.37] | [2.40] | [1.20] | [1.58] |
| *20* | 18.22 | 6.97 | 2.61 | 1.89 | 40.64 | 12.80 | 7.52 | 2.95 | 22.37 | 10.57 | 3.61 | 2.27 | 16.76 | 6.17 | 1.09 | 2.45 |
| | [3.68] | [2.33] | [1.53] | [0.80] | [4.13] | [2.88] | [1.77] | [0.97] | [3.61] | [2.76] | [1.61] | [1.15] | [4.39] | [2.37] | [1.20] | [1.63] |

*Notes*: This table reports the contribution of the short-run and long-run consumption and investment sector productivity shocks in explaining macroeconomic variables fluctuations. The estimated VAR includes sectoral TFP long-run components, sectoral TFP innovations and the growth rates of consumption, output, investment, and labor. Sectoral long-run risk components are estimated using the state-space approach defined in Section 5.1. Standard errors—obtained via Monte Carlo simulations (5000 repetitions)—are reported in square brackets. Data are quarterly and run from 1947:Q2 to 2016:Q1.

In general, the contribution of SR shocks is higher at short horizons. The opposite is true for LR shocks which, instead, tend to have a higher contribution at longer forecasting horizons. For instance, over the first quarter, LR investment shocks explain 11% of output variance. After 20 quarters their contribution increases to 13%. In total, SR (consumption and investment) shocks explain about 58% of output variance over the first quarter and about 48% over 20 quarters. LR (consumption and investment) shocks instead explain about 12% of output variance over the first quarter and about 16% over 20 quarters. The contribution of LR investment shocks to the fluctuations of investment remains relatively stable at around 12% over different forecasting horizons.

The standard errors of the estimated variance decomposition show that the contribution of LR investment shocks to macroeconomic variables is not only sizable but also statistically significant. Differently, the contribution of LR consumption shocks is generally not statistically significant and economically much less important than that of LR investment shocks. For instance, the fraction of output variance explained by LR investment shocks over 20 quarters is about four times bigger than the fraction of output variance explained by LR consumption shocks. It is even about 13 times bigger for a horizon of one quarter. This suggests that LR investment risk is both qualitatively and quantitatively important in explaining the fluctuations of macroeconomic variables.

# 6 Asset Prices

In this paper we are not only interested in the implications of SR and LR sectoral shocks for macroeconomic variables but also in their effect on asset prices, in particular the cross-section of stock returns. Our model predicts that the risk premium associated with SR and LR sectoral shocks is positive. The lower panels of Figure 1 depict the impulse response functions of the equilibrium pricing kernel with respect to sectoral SR and LR shocks. We see that SR and LR sectoral shocks decrease the pricing kernel on impact which means that those shocks are associated with states characterized by lower marginal utility. As a result, assets that are positively correlated with sectoral SR and LR shocks have lower prices, i.e., there is a positive risk premium for SR and LR shocks in the productivity of both sectors.

We test this prediction with standard cross-sectional regressions of stock returns. In our framework average returns are a function of four macro factors, namely SR and LR consumption shocks and SR and LR investment shocks. We therefore test the following factor model:

$$\mathbb{E}[R^{ei}] = \lambda \beta_i', \tag{17}$$

where $R^{ei}$ is the excess return of asset $i$, $\beta_i = [\beta_{\Delta TFP_c,i}, \beta_{x_c,i}, \beta_{\Delta TFP_I,i}, \beta_{x_I,i}]$ is the vector of risk exposures of asset $i$ containing the exposures of stock returns to sectoral shocks, and, finally, $\lambda = [\lambda_{\Delta TFP_c}, \lambda_{x_c}, \lambda_{\Delta TFP_I}, \lambda_{x_I}]$ is the vector of risk premia in which we are ultimately interested. We follow the classical two-stage regression approach. In the first stage, the betas are estimated from full-sample time series regressions:

$$R_t^{ei} = \alpha_i + \beta_{\Delta TFP_c,i} \Delta TFP_{c,t} + \beta_{x_c,i} x_{c,t} + \beta_{\Delta TFP_I,i} \Delta TFP_{I,t} + \beta_{x_I,i} x_{I,t} + \varepsilon_t^i, \quad \forall i. \tag{18}$$

The vector of risk premia is estimated from the cross-sectional second stage regression:

$$\mathbb{E}[R^{ei}] = \beta_{\Delta TFP_c,i} \lambda_{\Delta TFP_c} + \beta_{x_c,i} \lambda_{x_c} + \beta_{\Delta TFP_I,i} \lambda_{\Delta TFP_I} + \beta_{x_I,i} \lambda_{x_I} + \nu^i. \tag{19}$$

where $\mathbb{E}[R^{ei}]$ is the average return of each asset over time and the betas are taken from the first stage regression (18).

An alternative second stage regression is suggested by Fama and MacBeth (1973). Rather than estimating only one cross-sectional regression using time-series averages of stock returns, they suggest to run cross-sectional regressions at each time $t$, that is:

$$R_t^{ei} = \beta_{\Delta TFP_c,i}\lambda_{t,\Delta TFP_c} + \beta_{x_c,i}\lambda_{t,x_c} + \beta_{\Delta TFP_I,i}\lambda_{t,\Delta TFP_I} + \beta_{x_I,i}\lambda_{t,x_I} + \nu_t^i. \quad (20)$$

The estimator for $\lambda$ is then given by the average of the different cross-sectional estimates. We report estimates for this second approach as well. In principle, there are also two ways to estimate the betas: rolling-window (typically 5 years) or full-window estimates. Garlappi and Song (2016a) argue that with quarterly data the rolling-window approach is not applicable because the low frequency of data implies that there is not enough information to estimate the betas. For this reason we employ the full-sample approach only. In this case, the two different cross-sectional regressions yield the same estimates of risk premia, but different standard errors.

In our benchmark test, we use 25 portfolio sorted on size and book-to-market obtained from Ken French's webpage, which are typically used in the empirical asset pricing literature because they capture substantial cross-sectional variation in average returns. These portfolios are available for the sample period 1947–2015. The results of the estimation are reported in Table 5.

**Table 5: Sectoral Shocks and Stock Returns**
This table reports the exposures to short-run and long-run TFP shocks and the estimates of the market prices of risk. Test assets: 25 Portfolios sorted on size and book-to-market (Source: Kenneth R. French's Data Library). We use quarterly data for the period 1947:Q2–2015:Q4. The t-statistics of the average cross-sectional regression include the Shanken correction (Shanken, 1992) that accounts for possible estimation errors in the betas. The t-statistics of Fama-MacBeth regressions are corrected for cross-sectional correlation only.

| | Exposures to risk ($\beta$) | | | |
|---|---|---|---|---|
| | $\beta_c(SR)$ | $\beta_I(SR)$ | $\beta_c(LR)$ | $\beta_I(LR)$ |
| SizeBm1 | 1.121 | -0.368 | -0.530 | 0.386 |
| SizeBm2 | 0.808 | -0.083 | -1.060 | 0.457 |
| SizeBm3 | 0.819 | -0.235 | -0.936 | 0.961 |
| SizeBm4 | 0.600 | -0.094 | -0.406 | 0.901 |
| SizeBm5 | 0.688 | -0.060 | 0.123 | 0.859 |
| SizeBm6 | 0.990 | -0.464 | -1.369 | 0.515 |
| SizeBm7 | 0.621 | -0.179 | -0.505 | 0.035 |
| SizeBm8 | 0.560 | -0.134 | -0.352 | 0.525 |
| SizeBm9 | 0.511 | -0.081 | -0.055 | 0.496 |
| SizeBm10 | 0.486 | -0.053 | 0.866 | 0.347 |
| SizeBm11 | 0.707 | -0.315 | -0.476 | 0.057 |
| SizeBm12 | 0.661 | -0.272 | -0.596 | 0.503 |
| SizeBm13 | 0.423 | -0.064 | -0.045 | 0.280 |
| SizeBm14 | 0.465 | -0.109 | 0.393 | 0.283 |
| SizeBm15 | 0.366 | 0.061 | 0.099 | 0.389 |
| SizeBm16 | 0.666 | -0.310 | -0.741 | 0.461 |
| SizeBm17 | 0.511 | -0.215 | -0.110 | 0.524 |
| SizeBm18 | 0.292 | -0.046 | 1.215 | 0.382 |
| SizeBm19 | 0.350 | -0.105 | 0.677 | 0.992 |
| SizeBm20 | 0.325 | 0.197 | 1.205 | 0.067 |
| SizeBm21 | 0.524 | -0.176 | 0.254 | 0.361 |
| SizeBm22 | 0.343 | -0.179 | -0.064 | 0.399 |
| SizeBm23 | 0.326 | -0.078 | 1.239 | 0.201 |
| SizeBm24 | 0.248 | 0.020 | 1.166 | 0.226 |
| SizeBm25 | 0.288 | 0.214 | 0.964 | -0.382 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Average cross-sectional estimates) | 4.024 | 3.984 | 0.786 | 1.501 |
| t-stat | 1.564 | 1.629 | 1.736 | 2.562 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Fama-MacBeth) | 4.024 | 3.984 | 0.786 | 1.501 |
| t-stat | 3.775 | 3.931 | 4.175 | 6.248 |

First, the risk exposures (betas) to SR consumption shocks are positive while the risk exposures to LR consumption shocks are negative. Differently, the risk exposures to SR investment shocks are negative while the risk exposures to LR investment shocks are positive. The exposures of stock returns to SR investment shocks are consistent with the results of Papanikolaou (2011), Kogan and Papanikolaou (2013), and Segal (2015). The similarity of our results with those of Papanikolaou (2011) and Kogan and Papanikolaou

(2013) further confirms that MEI shocks and SR shocks to the TFP process of the investment sector have similar implications not only for the dynamics of macroeconomic variables but also for stock returns.

The estimated risk premia are positive and significant, consistent with the predictions of our theoretical model. To assess the robustness of this result we repeat the test for different portfolios: 25 portfolios sorted on book-to-market and investments, 25 portfolios sorted on book-to-market and operating profitability, and 25 portfolios sorted on investment and operating profitability. These alternative portfolios are only available for the sample period 1965–2015. Thus, for completeness, we also repeat our benchmark test for the more recent sample period 1965–2015. The results of these robustness tests are reported in Appendix D. The results are qualitatively similar, but the estimates are slightly less significant due to the smaller sample size. In two cases (25 portfolios sorted on book-to-market and investment and 25 portfolios sorted on investment and operating profitability) the estimated risk premium of SR investment shocks changes sign and becomes negative, but it is not significant. This result might shed more light on the mixed evidence concerning the sign of the risk premium of investment-specific shocks. Our findings suggest that the negative risk premium might arise, at least in some cases, only from SR investment shocks while LR investment shocks are more consistently associated with positive and significant risk premia.

# 7 Conclusion

In this paper we propose a new source of technology shocks, namely long-run investment risk, that is important for our understanding of macroeconomic fluctuations as well as the dynamics of asset prices. Long-run investment shocks differ from shocks to the marginal efficiency of investment, which are typically analyzed in the existing literature. Shocks to the marginal efficiency affect the current profitability of the investment sector. Differently, long-run investment TFP shocks affect the future expected profitability of investments. Naturally, one can debate which one of the two approaches describes the statistical properties of the investment sector in a more realistic way. But more importantly, the two approaches offer different explanations for the economic link between the risk of the investment sector, business cycles, and asset prices. Shocks to the marginal efficiency of investments affect output and asset prices "only to the extent that they are implemented through the formation of new capital stock" (Papanikolaou, 2011). Differently, long-run investment shocks alter the perception regarding long-term productivity, and this effect, which goes above and beyond the effect of investment shocks for the cost of producing new capital, is qualitatively and quantitatively important for explaining the fluctuation of macroeconomic variables and the cross-section of stock returns.

Our newly proposed channel is not only in line with the idea of investment hysteresis, but is also corroborated by empirical evidence using sectoral TFP data. We estimate a vector autoregression mimicking our theoretical model and find that the empirical impulse responses are in line with the predictions of our model. Moreover, in cross-sectional regressions, we find that short-run and long-run risk are priced in financial markets and that their risk premia are positive. Given the theoretical and empirical evidence, we think that long-run investment shocks are a very natural modelling choice, and they could represent an interesting avenue of future research.

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# A Equilibrium Equations

The equilibrium allocation in this economy consists of (i) time paths of consumption, total labor hours, labor hours supplied to the consumption goods sector and investment goods sector, and utility flow $\{C_t, L_t, L_{C,t}, L_{I,t}, v_t\}_{t=0}^{t=\infty}$, (ii) time paths of consumption goods output, physical capital, investment and new capital created $\{Y_{C,t}, K_{C,t}, I_{C,t}, G_t\}_{t=0}^{t=\infty}$, (iii) time paths of investment goods output and investment goods price $\{Y_{I,t}, P_{I,t}\}_{t=0}^{t=\infty}$, (iv) time paths of dividends and cum-dividend stock prices for the consumption and investment goods sector, as well as the aggregate market $\{D_{C,t}, V_{C,t}, D_{I,t}, V_{I,t}, D_{M,t}, V_{M,t}\}_{t=0}^{t=\infty}$, and (v) time paths of the pricing kernel in consumption and utility flow units, the wealth to utility flow ratio, the return on wealth, and the risk-free rate $\left\{\mathbb{M}_{t,t+1}, \mathbb{M}_{t,t+1}^{(v)}, u_t, R_t^W, R_{f,t}\right\}_{t=0}^{t=\infty}$, such that (a) the representative household maximizes lifetime utility (1), (b) the consumption goods sector maximizes its value (6), and (c) the investment goods sector maximizes its value (11).

This implies that the equilibrium is determined by a system of 25 equations for 25 variables, $v_t$, $R_t^W$, $C_t$, $L_t$, $L_{C,t}$, $L_{I,t}$, $W_t^u$, $W_t$, $Y_{C,t}$, $Y_{I,t}$, $K_{C,t+1}$, $I_{C,t}$, $P_{I,t}$, $\lambda_t$, $\mathbb{M}_{t,t+1}$, $\mathbb{M}_{t,t+1}^{(v)}$, $u_t$, $D_{C,t}$, $V_{C,t}$, $D_{I,t}$, $V_{I,t}$, $D_{M,t}$, $V_{M,t}$, $G_t$, and $R_{f,t}$, given the endogenous state variable $K_{C,t}$ and five exogenous state variables $A_{C,t}, A_{I,t}, Z_{M,t}, x_{C,t}, x_{I,t}$. Below we report the equations for the full economy with MEI shocks. The equations for the benchmark economy follow by setting $Z_{M,t} = 1$.

1. Conditions for the household's maximization problem and related Euler equations:

$$W_t^u = \frac{1-\nu}{\nu}\left(\frac{C_t}{\bar{L} - L_t}\right),$$

$$W_t = \left(W_{t-1}\frac{A_{C,t}}{A_{C,t-1}}\right)^{\xi} (W_t^u)^{1-\xi},$$

$$
\begin{aligned}
v_t &= C_t^{\nu} \left( A_{C,t}(\bar{L} - L_t) \right)^{1-\nu}, \\
u_t &= 1 + \mathbb{E}_t \left[ \mathbb{M}_{t,t+1}^{(v)} u_{t+1} \frac{v_{t+1}}{v_t} \right], \\
R_t^W &= \frac{u_t + \frac{v_t}{v_{t-1}}}{u_{t-1} - 1}, \\
\mathbb{M}_{t,t+1} &= \beta \left( \frac{C_{t+1}}{C_t} \right)^{-1} \left( \frac{v_{t+1}}{v_t} \right)^{1-\frac{1}{\psi}} \left( \frac{U_{t+1}}{[\mathbb{E}_t U_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}} \right)^{\frac{1}{\psi}-\gamma} = \beta^{\theta} \left( \frac{v_{t+1}}{v_t} \right)^{1-\frac{\theta}{\psi}} \left( \frac{C_{t+1}}{C_t} \right)^{-1} \left( R_{t+1}^W \right)^{\theta-1}, \\
\mathbb{M}_{t,t+1}^{(v)} &= \beta^{\theta} \left( \frac{v_{t+1}}{v_t} \right)^{-\frac{\theta}{\psi}} \left( R_{t+1}^W \right)^{\theta-1}, \\
\frac{1}{R_t^f} &= \mathbb{E}_t[\mathbb{M}_{t,t+1}].
\end{aligned}
$$

2. Conditions for the maximization problem of the consumption good firm and related equations:

$$
\begin{aligned}
W_t &= \frac{(1-\alpha_C) Y_{C,t}}{L_{C,t}}, \\
Y_{C,t} &= K_{C,t}^{\alpha_C} \left( A_{C,t} L_{C,t} \right)^{1-\alpha_C}, \\
K_{C,t+1} &= (1-\delta_K) K_{C,t} + G_t K_{C,t}, \\
G_t &= \frac{\alpha_1}{1-\frac{1}{\tau}} \left( \frac{I_{C,t}}{K_{C,t}} \right)^{1-\frac{1}{\tau}} + \alpha_2, \\
1 &= \mathbb{E}_t \left[ \mathbb{M}_{t,t+1} \frac{1}{\lambda_t} \left( \frac{\alpha_C Y_{C,t+1} - Z_{M,t+1}^{-1} P_{I,t+1} I_{C,t+1}}{K_{C,t+1}} + \lambda_{t+1}(G_{t+1} + 1 - \delta_K) \right) \right], \\
\lambda_t &= \frac{P_{I,t} Z_{M,t}^{-1}}{G_t'}, \\
D_{C,t} &= Y_{C,t} - Z_{M,t}^{-1} P_{I,t} I_{C,t} - W_t L_{C,t}, \\
V_{C,t} &= D_{C,t} + \mathbb{E}_t[\mathbb{M}_{t,t+1} V_{C,t+1}].
\end{aligned}
$$

3. Conditions for the maximization problem of the investment good firm and related equations:

$$
\begin{aligned}
W_t &= \frac{(1-\alpha_I)P_{I,t}Y_{I,t}}{L_{I,t}}, \\
Y_{I,t} &= A_{I,t}L_{I,t}^{1-\alpha_I}, \\
D_{I,t} &= P_{I,t}Y_{I,t} - W_tL_{I,t}, \\
V_{I,t} &= D_{I,t} + \mathbb{E}_t[\mathbb{M}_{t,t+1}V_{I,t+1}].
\end{aligned}
$$

4. Market clearing conditions and aggregate dividend:

$$
\begin{aligned}
L_t &= L_{C,t} + L_{I,t}, \\
Y_{I,t} &= Z_{M,t}^{-1}I_{C,t}, \\
C_t &= Y_{C,t} = W_tL_t + D_{M,t} = W_tL_t + D_{C,t} + D_{I,t}, \\
D_{M,t} &= D_{C,t} + D_{I,t}, \\
V_{M,t} &= D_{M,t} + \mathbb{E}_t[\mathbb{M}_{t,t+1}V_{M,t+1}].
\end{aligned}
$$

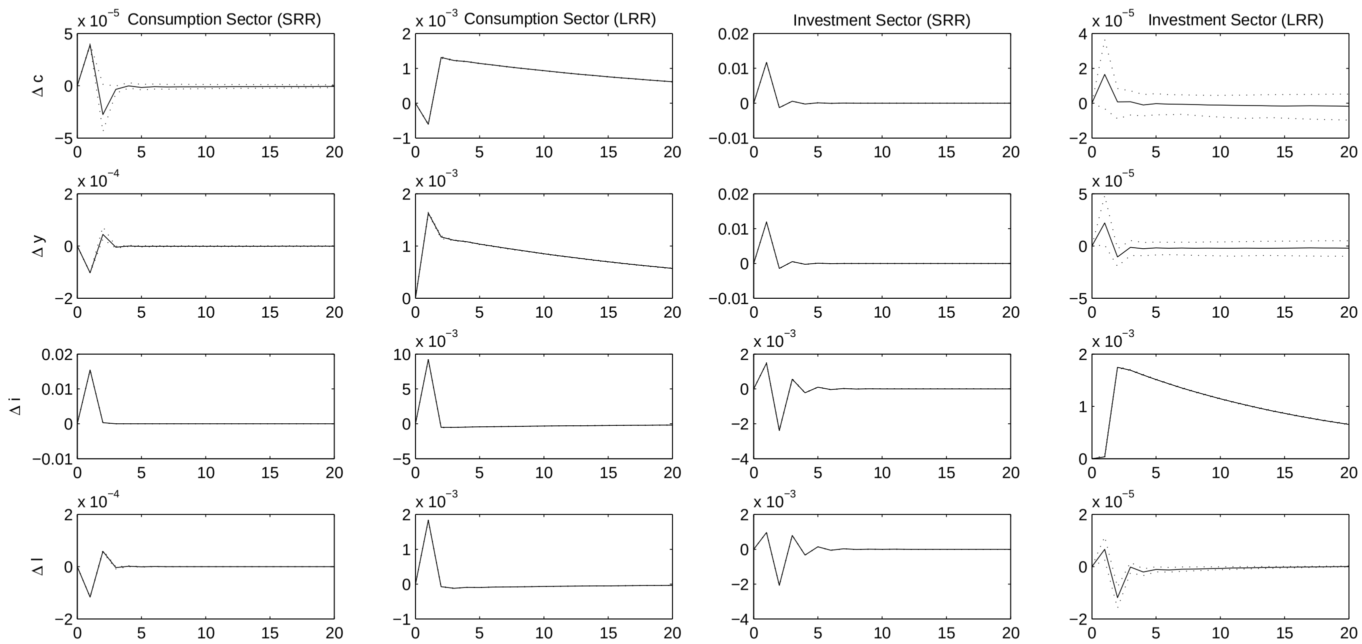
5. Evolution of the five exogenous state variables:

$$
\begin{aligned}
\log(A_{C,t}) &= \mu_C + x_{C,t-1} + \log(A_{C,t-1}) + \sigma_C\varepsilon_{C,t}, \\
x_{C,t} &= \rho_C x_{C,t-1} + \sigma_{x,C}\varepsilon_{x,C,t}, \\
\log(A_{I,t}) &= \mu_I + x_{I,t-1} + \log(A_{I,t-1}) + \sigma_I\varepsilon_{I,t}, \\
x_{I,t} &= \rho_I x_{I,t-1} + \sigma_{x,I}\varepsilon_{x,I,t}, \\
\log(Z_{M,t}) &= \rho_M \log(Z_{M,t-1}) + \sigma_M\varepsilon_{M,t}.
\end{aligned}
$$

# B Robustness Tests

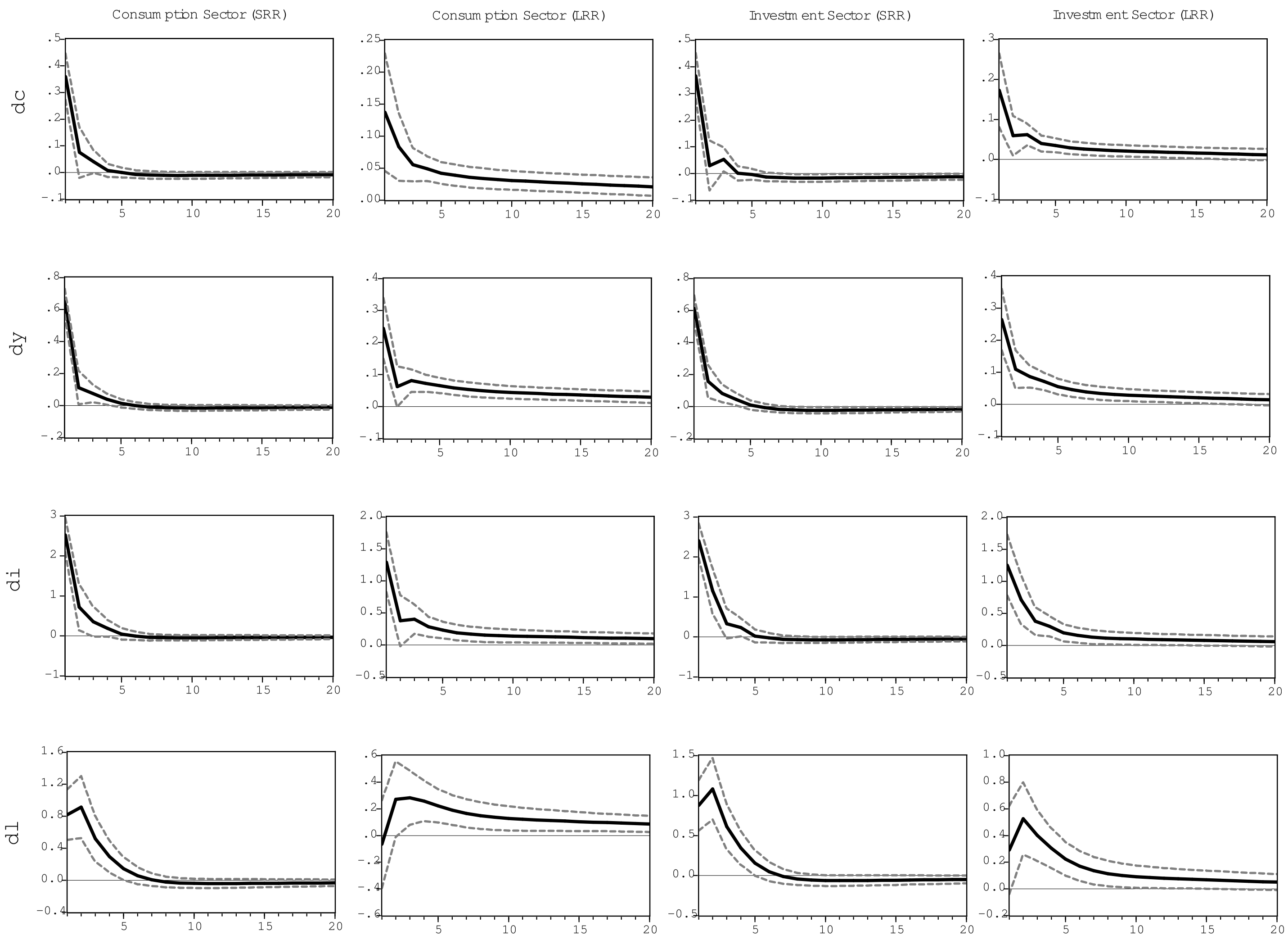
The following two figures provide two robustness checks for the main analyses discussed in Sections 4 and 5. In particular, Figure B.1 depicts the impulse response functions of the model obtained by estimating a VAR on simulated data from the model. Moreover, Figure B.2 depicts the generalized impulse response functions from the VAR estimated from real data.

**Figure B.1:** Model-implied impulse responses to short-run and long-run sectoral productivity shocks (VAR8).




*Notes*: Population (Cholesky orthogonalized) impulse responses of consumption growth, output growth, investment growth, and labor growth to one-standard deviation consumption TFP short-run and long-run and investment TFP short-run and long-run shocks. Dashed lines represent 95% confidence intervals. Data are obtained from a long sample simulation. The horizontal axis represents quarters. The VAR estimation includes a constant.

**Figure B.2:** EMPIRICAL (GENERALIZED) IMPULSE RESPONSES TO SHORT-RUN AND LONG-RUN SECTORAL PRODUCTIVITY SHOCKS (VAR8).




*Notes*: This figure depicts generalized impulse responses of consumption growth, output growth, investment growth, and labor growth to one-standard deviation consumption TFP short-run and long-run and investment TFP short-run and long-run shocks. The horizontal axis represents quarters. The gray dashed lines and the dotted black lines represent 95% confidence bands and point estimates, respectively. The data are quarterly and run from 1947:Q2 to 2016Q1. The VAR estimation includes a constant.

# C Data

Sectoral TFP growth rates are from Fernald (2012). Data are freely available at annual and quarterly frequency from the Federal Reserve Bank of San Fransisco. To estimate short-run and long-run risk shocks quarterly sectoral TFP data for the period 1947:Q2–2016:Q1 are employed. The macroeconomic aggregates employed in the VAR analysis have been retrieved from the US Bureau of Economic Analysis and cover the period 1947:Q2–2016:Q1. Consumption, output, and investment growth rates (i.e., $\Delta c$, $\Delta y$, $\Delta i$) are computed from Real Personal Consumption Expenditures (Series ID: PCECC96; Seasonal Adjustment: Seasonally Adjusted Annual Rate; Units: Billions of Chained 2009 Dollars), Real Gross Domestic Product (Series ID: GDPC1; Seasonal Adjustment: Seasonally Adjusted Annual Rate; Units: Billions of Chained 2009 Dollars), and Real Gross Private Domestic Investment (Series ID: GPDIC1; Seasonal Adjustment: Seasonally Adjusted Annual Rate; Units: Billions of Chained 2009 Dollars), respectively. Labor supply is measured as non-farm business hours. The labor supply quarterly growth rate (i.e., $\Delta l$) is obtained from the "Nonfarm Business Sector: Hours of All Persons index" (Series ID: HOANBS; Seasonal Adjustment: Seasonally Adjusted; Units: Index 2009=100) downloaded from the US Bureau of Labor Statistics (BLS).

# D Additional cross-sectional tests

**Table D.1: 25 Portfolios sorted on Size and Book-to-Market: Short sample**
This table reports the exposures to short-run and long-run sector shocks and the estimates of the market prices of risk. Test assets: 25 Portfolios sorted on Size and Book-to-Market (Source: Kenneth R. French's Data Library). Quarterly data for the period 1965:Q1–2015:Q4 are used. The t-statistics of the average cross-sectional regression include the Shanken correction (Shanken, 1992) that accounts for possible estimation errors in the betas. The t-statistics of Fama-MacBeth regressions are corrected for cross-sectional correlation only.

| | Exposures to risk ($\beta$) | | | |
|---|---|---|---|---|
| | $\beta_c(SR)$ | $\beta_I(SR)$ | $\beta_c(LR)$ | $\beta_I(LR)$ |
| SizeBm1 | 1.838 | -0.997 | 0.160 | 0.639 |
| SizeBm2 | 1.623 | -0.807 | -0.859 | 1.083 |
| SizeBm3 | 1.413 | -0.795 | -0.333 | 1.345 |
| SizeBm4 | 1.249 | -0.700 | 0.455 | 1.304 |
| SizeBm5 | 1.364 | -0.645 | 1.029 | 1.155 |
| SizeBm6 | 1.699 | -1.040 | -1.069 | 0.812 |
| SizeBm7 | 1.255 | -0.747 | -0.902 | 0.607 |
| SizeBm8 | 1.117 | -0.656 | 0.485 | 0.838 |
| SizeBm9 | 1.035 | -0.638 | 0.764 | 0.744 |
| SizeBm10 | 0.972 | -0.569 | 1.749 | 0.578 |
| SizeBm11 | 1.610 | -1.018 | -1.476 | 0.972 |
| SizeBm12 | 1.253 | -0.809 | -0.213 | 0.840 |
| SizeBm13 | 0.937 | -0.540 | -0.019 | 0.782 |
| SizeBm14 | 1.003 | -0.651 | 1.265 | 0.558 |
| SizeBm15 | 0.925 | -0.573 | 0.422 | 0.822 |
| SizeBm16 | 1.381 | -0.917 | -1.812 | 1.369 |
| SizeBm17 | 1.126 | -0.771 | -0.937 | 1.297 |
| SizeBm18 | 0.737 | -0.509 | 1.302 | 0.865 |
| SizeBm19 | 0.801 | -0.612 | 2.024 | 1.030 |
| SizeBm20 | 0.774 | -0.278 | 1.623 | 0.160 |
| SizeBm21 | 1.098 | -0.605 | -1.051 | 0.990 |
| SizeBm22 | 0.884 | -0.747 | -1.311 | 1.266 |
| SizeBm23 | 0.747 | -0.520 | 0.282 | 0.909 |
| SizeBm24 | 0.570 | -0.388 | 1.086 | 0.525 |
| SizeBm25 | 0.602 | -0.089 | 0.341 | -0.336 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Average cross-sectional estimates) | 2.345 | 1.915 | 0.678 | 1.413 |
| t-stat | 1.316 | 0.925 | 1.944 | 2.600 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Fama-MacBeth) | 2.345 | 1.915 | 0.678 | 1.413 |
| t-stat | 3.098 | 2.184 | 4.646 | 6.135 |

**Table D.2: 25 Portfolios sorted on Book-to-Market and Investment**
This table reports the exposures to short-run and long-run sector shocks and the estimates of the market prices of risk. Test assets: 25 Portfolios sorted on Book-to-Market and Investment (Source: Kenneth R. French's Data Library). Quarterly data for the period 1965:Q1–2015:Q4 are used.The t-statistics of the average cross-sectional regression include the Shanken correction (Shanken, 1992) that accounts for possible estimation errors in the betas. The t-statistics of Fama-MacBeth regressions are corrected for cross-sectional correlation only.

| | Exposures to risk ($\beta$) | | | |
|---|---|---|---|---|
| | $\beta_c(SR)$ | $\beta_I(SR)$ | $\beta_c(LR)$ | $\beta_I(LR)$ |
| BmInv1 | 1.380 | -0.902 | -2.890 | 1.082 |
| BmInv2 | 0.945 | -0.635 | -1.040 | 0.649 |
| BmInv3 | 0.927 | -0.551 | -0.660 | 0.768 |
| BmInv4 | 1.174 | -0.716 | -1.615 | 1.830 |
| BmInv5 | 1.424 | -0.763 | -1.540 | 1.025 |
| BmInv6 | 1.250 | -0.772 | -1.020 | 0.883 |
| BmInv7 | 0.947 | -0.827 | -2.275 | 1.630 |
| BmInv8 | 0.900 | -0.789 | -1.548 | 1.460 |
| BmInv9 | 1.005 | -0.880 | -0.093 | 1.353 |
| BmInv10 | 0.974 | -0.520 | -0.471 | 0.704 |
| BmInv11 | 0.895 | -0.640 | 0.240 | 0.892 |
| BmInv12 | 0.781 | -0.515 | -0.216 | 0.775 |
| BmInv13 | 0.888 | -0.563 | -0.601 | 1.497 |
| BmInv14 | 0.858 | -0.682 | 0.359 | 1.176 |
| BmInv15 | 0.765 | -0.380 | 2.463 | 0.189 |
| BmInv16 | 0.901 | -0.427 | 0.982 | 0.244 |
| BmInv17 | 0.518 | -0.491 | 2.014 | 0.387 |
| BmInv18 | 0.725 | -0.429 | 1.583 | 0.830 |
| BmInv19 | 0.927 | -0.639 | 1.162 | 1.762 |
| BmInv20 | 0.837 | -0.429 | 1.559 | -0.121 |
| BmInv21 | 0.968 | -0.356 | 0.759 | -0.207 |
| BmInv22 | 0.965 | -0.485 | -0.299 | 0.548 |
| BmInv23 | 0.715 | -0.201 | 1.011 | 0.403 |
| BmInv24 | 1.013 | -0.586 | 1.055 | 1.003 |
| BmInv25 | 0.953 | -0.346 | 1.701 | 0.005 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Average cross-sectional estimates) | 2.318 | -0.131 | 0.383 | 0.238 |
| t-stat | 1.780 | -0.099 | 1.719 | 0.670 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Fama-MacBeth) | 2.318 | -0.131 | 0.383 | 0.238 |
| t-stat | 3.377 | -0.185 | 3.301 | 1.269 |

**Table D.3: 25 Portfolios sorted on Book-to-Market and Operating Profitability**
This table reports the exposures to short-run and long-run sector shocks and the estimates of the market prices of risk. Test assets: 25 Portfolios sorted on Book-to-Market and Operating profitability (Source: Kenneth R. French's Data Library). Quarterly data for the period 1965:Q1–2015:Q4 are used. The t-statistics of the average cross-sectional regression include the Shanken correction (Shanken, 1992) that accounts for possible estimation errors in the betas. The t-statistics of Fama-MacBeth regressions are corrected for cross-sectional correlation only.

| | Exposures to risk ($\beta$) | | | |
|---|---|---|---|---|
| | $\beta_c(SR)$ | $\beta_I(SR)$ | $\beta_c(LR)$ | $\beta_I(LR)$ |
| BmOP1 | 2.082 | -1.099 | -1.839 | 2.265 |
| BmOP2 | 1.303 | -0.888 | -2.834 | 1.993 |
| BmOP3 | 1.178 | -0.688 | -0.966 | 0.798 |
| BmOP4 | 1.194 | -0.693 | -2.119 | 1.200 |
| BmOP5 | 1.105 | -0.646 | -0.780 | 1.013 |
| BmOP6 | 1.356 | -0.757 | -0.640 | 0.586 |
| BmOP7 | 1.106 | -0.821 | -1.849 | 1.012 |
| BmOP8 | 0.840 | -0.585 | -1.427 | 0.765 |
| BmOP9 | 0.893 | -0.655 | -0.825 | 1.218 |
| BmOP10 | 0.965 | -0.936 | 0.017 | 1.663 |
| BmOP11 | 0.767 | -0.508 | -0.658 | 0.821 |
| SizeBm12 | 0.746 | -0.405 | -0.045 | 0.439 |
| BmOP13 | 0.910 | -0.774 | 0.238 | 1.420 |
| BmOP14 | 0.762 | -0.554 | 1.602 | 0.982 |
| BmOP15 | 1.063 | -0.487 | 0.297 | 0.657 |
| BmOP16 | 0.507 | -0.136 | 1.963 | -0.057 |
| BmOP17 | 0.644 | -0.479 | 1.360 | 0.750 |
| BmOP18 | 0.804 | -0.580 | 1.375 | 1.256 |
| BmOP19 | 0.956 | -0.711 | 0.299 | 1.284 |
| BmOP20 | 1.001 | -0.354 | 3.717 | -0.142 |
| BmOP21 | 0.646 | -0.293 | 1.769 | -0.127 |
| BmOP22 | 0.865 | -0.548 | 1.524 | 0.592 |
| BmOP23 | 1.318 | -0.460 | -0.873 | -0.194 |
| BmOP24 | 1.546 | -0.506 | -4.115 | 1.969 |
| BmOP25 | 1.652 | -0.584 | -0.752 | 0.598 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Average cross-sectional estimates) | 2.384 | 0.727 | 0.457 | 0.371 |
| t-stat | 2.090 | 0.441 | 2.657 | 0.979 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Fama-MacBeth) | 2.384 | 0.727 | 0.457 | 0.371 |
| t-stat | 3.599 | 0.769 | 4.608 | 1.702 |

**Table D.4: 25 Portfolios Sorted on Investment and Operating Profitability**
This table reports the exposures to short-run and long-run sector shocks and the estimates of the market prices of risk. Test assets: 25 Portfolios sorted on Investment and Operating Profitability (Source: Kenneth R. French's Data Library). Quarterly data for the period 1965:Q1–2015:Q4 are used. The t-statistics of the average cross-sectional regression include the Shanken correction (Shanken, 1992) that accounts for possible estimation errors in the betas. The t-statistics of Fama-MacBeth regressions are corrected for cross-sectional correlation only.

| | Exposures to risk ($\beta$) | | | |
|---|---|---|---|---|
| | $\beta_c(SR)$ | $\beta_I(SR)$ | $\beta_c(LR)$ | $\beta_I(LR)$ |
| InvOP1 | 0.953 | -0.289 | 0.289 | 0.081 |
| InvOP2 | 0.511 | -0.256 | 0.932 | 0.062 |
| InvOP3 | 0.949 | -0.580 | 1.166 | 1.297 |
| InvOP4 | 0.905 | -0.482 | 1.975 | 0.879 |
| InvOP5 | 1.266 | -0.654 | 0.764 | -0.044 |
| InvOP6 | 0.693 | -0.367 | -0.131 | 0.800 |
| InvOP7 | 0.941 | -0.582 | -0.214 | 1.034 |
| InvOP8 | 0.809 | -0.493 | -0.588 | 0.869 |
| InvOP9 | 1.083 | -0.934 | -0.735 | 1.965 |
| InvOP10 | 0.982 | -0.606 | 0.126 | 0.369 |
| InvOP11 | 1.116 | -0.716 | -0.861 | 0.747 |
| InvOP12 | 0.857 | -0.807 | -1.027 | 1.840 |
| InvOP13 | 0.874 | -0.551 | -0.179 | 0.698 |
| InvOP14 | 0.788 | -0.468 | 0.641 | 0.536 |
| InvOP15 | 1.201 | -0.564 | -1.030 | 0.338 |
| InvOP16 | 1.172 | -0.746 | 0.097 | 0.752 |
| InvOP17 | 0.694 | -0.450 | -1.223 | 1.353 |
| InvOP18 | 1.043 | -0.686 | -1.995 | 1.076 |
| InvOP19 | 0.859 | -0.516 | -1.074 | 1.823 |
| InvOP20 | 1.372 | -0.788 | -1.235 | 0.798 |
| InvOP21 | 1.266 | -0.841 | -0.516 | -0.021 |
| InvOP22 | 0.827 | -0.577 | -0.268 | 0.062 |
| InvOP23 | 0.749 | -0.501 | 0.357 | 1.168 |
| InvOP24 | 1.392 | -0.890 | -1.383 | 1.888 |
| InvOP25 | 1.281 | -0.742 | -1.364 | 1.622 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Average cross-sectional estimates) | 1.415 | -0.902 | 0.222 | 0.386 |
| t-stat | 0.744 | -0.497 | 0.916 | 1.411 |
| Risk premium ($\lambda$) | $\lambda_c(SR)$ | $\lambda_I(SR)$ | $\lambda_c(LR)$ | $\lambda_I(LR)$ |
| (Fama-MacBeth) | 1.4145 | -0.902 | 0.222 | 0.386 |
| t-stat | 1.489 | -0.987 | 1.832 | 2.682 |