Investment-Specific Shocks, Business Cycles and Asset Prices

Giuliano Curatola, Michael Donadelli,
Patrick Grüning, and Christoph Meinerding*

This version: September 8, 2015

Abstract

We explore the implications of long-run investment productivity risk for the joint dynamics of asset prices and macroeconomic quantities in a two-sector production economy model. Long-run productivity risk in both sectors, for which we provide economic and empirical justification, acts as a substitute for shocks to the marginal efficiency of investments when it comes to explaining the equity premium and the stock return volatility differential between the consumption and the investment sector. In addition, the positive co-movement between consumption and investment growth can be obtained by coupling long-run productivity risk with a moderate degree of nominal rigidities.

Keywords: General equilibrium asset pricing, production economy, long-run risk, investment-specific shocks, nominal rigidities

JEL: E32, G12

---

*Donadelli is at the Research Center SAFE, Curatola and Meinerding at the Department of Finance at Goethe University Frankfurt, 60323 Frankfurt am Main, Germany, Grüning is at the Center for Excellence in Finance and Economic Research (CEFER) of the Bank of Lithuania, and at the Faculty of Economics at Vilnius University. Economic Authors' e-mails and phone numbers: `curatola@safe.uni-frankfurt.de`, +49 (0)69-798-30096; `donadelli@safe.uni-frankfurt.de`, +49 (0)69-798-33882; `PGruening@lb.lt`, +370 5-2680-069; `meinerding@finance.uni-frankfurt.de`, +49 (0)69-798-33730. We thank Roberto Pancrazi for helpful comments and criticism. We gratefully acknowledge research and financial support from the Research Center SAFE, funded by the State of Hessen initiative for research LOEWE. The views expressed herein are solely those of the authors and do not necessarily reflect the views of the Bank of Lithuania or the Eurosystem.

1 Introduction

Investment-specific shocks have been shown to be an important driver for the dynamics of asset prices and macroeconomic quantities in general equilibrium models. Papanikolaou (2011) argues that investment shocks can simultaneously reproduce the value premium and other moments of stock returns as well as the co-movement of key macroeconomic quantities. Justiniano et al. (2010, 2011) find that investment shocks are the main driver of business cycle fluctuations in the US economy. However, conventional models that attribute a central role to investment shocks tend to produce a negative correlation between consumption and investment, contrary to the empirical evidence.[1] Moreover, in the model of Papanikolaou (2011) shocks to the total factor productivity (TFP) of the investment sector cannot explain the basic unconditional moments of equity returns unless an additional source of uncertainty is added to the model, in this case shocks to the marginal efficiency of investments.[2]

In this paper we propose a dynamic stochastic general equilibrium (DSGE) model with two sectors that bridges an important gap in the literature by analyzing the joint effect of investment shocks on both asset prices and macroeconomic quantities. We proceed in two steps. First, we assume that the TFP of both the consumption and the investment sector are driven by short- and long-run components. This assumption is motivated by the empirical evidence of Greenwood et al. (2000) and Croce (2014). Theoretically, the presence of a long-run component in the productivity of investments can also be deduced from the idea of investment hysteresis originally proposed by Dixit (1992).[3] We also estimate the TFP processes using sectoral output data and confirm the presence of a long-run risk component in the TFP process of both the consumption and the investment sector.

---

[1] This co-movement problem is well documented by Khan and Tsoukalas (2011), Furlanetto et al. (2013) and Furlanetto and Seneca (2014a,b).

[2] More precisely Papanikolaou (2011) shows that when the marginal efficiency of investment is deterministic one would need an unrealistic high volatility of TFP shocks in the investment sector to match the equity premium and volatility of stock returns.

[3] The traditional theory of investment 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, the 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. This suggests that investment drivers may have long-lasting effects.

Second, we add some moderate frictions to the model, in particular capital adjustment costs in the spirit of Jermann (1998) and moderate wage rigidities as suggested by Uhlig (2007).

The presence of long-run risk in the consumption sector, together with capital adjustment costs, allows the model to generate a sizeable equity premium and a low and stable risk-free rate. Introducing long-run risk in the investment sector then helps to reproduce the empirically observed spread in the stock return volatilities of the two sectors. Both results can be obtained without assuming a stochastic marginal efficiency of investment. Moreover, long-run risk in the consumption and in the investment sector allows us to obtain these results with a relatively moderate degree of capital adjustment costs. However, long-run risk alone does not resolve the macroeconomic co-movement problem and the correlation between consumption and investment remains negative. Adding moderate wage rigidities makes this correlation positive. Short-run investment shocks tend to produce negative co-movement between consumption and investment, while long-run investment shocks result in positive co-movement. The tradeoff between these two effects can be controlled by varying the degree of wage rigidities in the model. Finally, making the marginal efficiency of investment stochastic enables the model to replicate the empirically high volatility of investment growth.

Our results contribute to the recent literature that tries to improve the empirical predictions of general equilibrium models with investment shocks. Khan and Tsoukalas (2011) suggest that the co-movement problem can be solved when the cost of capital utilization is defined in terms of capital depreciation. Furlanetto and Seneca (2014a) argue that a positive co-movement between consumption and investment obtains in models with price rigidities. Finally, Furlanetto et al. (2013) propose an explanation for the co-movement problem that relies on rule-of-thumb households who do not use financial markets to smooth consumption, but spend their entire income in each period to finance consumption. However, these papers do not analyze any asset pricing moments and thus remain silent about the implications of their proposed explanation of the co-movement problem for financial markets.

On the other hand, the recent asset pricing literature is more concerned with the implications of investment shocks for the moments of stock returns than with their implications for macroeconomic quantities. For instance, the model proposed by Papanikolaou (2011) matches the correlation between consumption, investment, and output growth, but only with a stochastic marginal efficiency of investment. Moreover, the model does not match the correlation between consumption and hours worked. Kogan and Papanikolaou (2014) show that investment shocks have explanatory power for the cross-section of stock returns. However, they do not analyze the implications of investment shocks for macroeconomic co-movements. We try to fill the gap in the literature by analyzing the joint effect of investment shocks on both asset prices and macroeconomic quantities. After all, investment shocks have been advocated not only as an important driver of the business cycle but also as a driver of expected stock returns and return volatilities. Therefore a consistent explanation of macroeconomic co-movements that relies on investment shocks should also be able to provide a reasonable fit for the key moments of asset prices, and vice versa. Our results suggest that investment shocks contribute a great deal to explaining the dynamics of asset prices, but need to be coupled with nominal rigidities (or other sources of market imperfections) to generate realistic macroeconomic co-movements.

The rest of the paper is organized as follows. Section 2 describes the economy. The calibration of the model is dicussed in Section 3. In Section 4 we analyze the quantitative implications of our model. Section 5 concludes.

2 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 different shocks to investment good productivity and efficiency. The first sector is the consumption good sector. It admits a fairly standard competitive representative firm that uses capital and labor to produce consumption goods which it supplies to the representative household for consumption. The second sector is the investment good sector. It uses labor to produce investment goods which it sells to the consumption good sector at a monopolistic price. The representative household owns both sectors, has recursive preferences over consumption and leisure and freely allocates labor to the two sectors. The production technologies in both sectors are subject to both short- and long-run productivity shocks. Moreover, the marginal efficiency of investment is allowed to be stochastic.

The model most closely related to ours is developed in Papanikolaou (2011). However, we depart from it in several dimensions. First, the utility flow of the representative household's recursive preferences is given by a Cobb-Douglas aggregate over consumption and leisure. Second, we use capital adjustment costs as in Jermann (1998). Third, we incorporate long-run productivity shocks in the consumption good sector as in Croce (2014). Fourth, similarly to the consumption good sector, we allow for long-run shocks in investment productivity as well. To the best of our knowledge, there is no model featuring this kind of shocks in investment good productivity and, hence, the asset pricing implications of these shocks are unknown. Finally, in the spirit of Uhlig (2007), we account for labor market rigidities. A summary of the equilibrium conditions and details about the solution of the model are provided in Appendix A.

2.1 Representative Household

The representative agent has recursive preferences as in Epstein and Zin (1989) over the utility flow v_t

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

where γ denotes relative risk aversion (RRA), ψ measures the intertemporal elasticity of substitution (IES), and $\beta \in (0,1)$ is the household's subjective discount factor. Notice that this preference specification allows to separate the relative risk aversion (RRA) from the intertemporal elasticity of substitution (IES), and has been widely used in recent asset pricing and RBC/IBC studies.[4] Notice also that this class of preferences has been recently

---

[4] See, e.g., Bansal and Yaron (2004), Papanikolaou (2011), Caldara et al. (2012), Colacito and Croce (2013), Kung and Schmid (2015).

supported by experimental studies.[5] The standard expected utility model is nested under the assumption $\gamma = \frac{1}{\psi}$. The utility flow, $v_t := v(C_t, L_t)$, is a Cobb-Douglas index of aggregate consumption C_t and leisure $1 - L_t$

$$v(C_t, L_t) = C_t^{\nu} \left(A_{t-1}(1 - L_t)\right)^{1-\nu},$$

where $\nu \in (0, 1)$ reflects preferences for consumption versus leisure. A_t is the productivity of the consumption good sector and will be discussed below.

In each period, the representative household chooses consumption C_t and labor L_t to maximize (1) subject to the following budget constraint

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

where $\vartheta_{C,t}$ ($\vartheta_{I,t}$) denotes equity shares in the representative consumption (investment) good sector firm held from time $t-1$ to time t, $V_{C,t}$ ($V_{I,t}$) is the cum-dividend market value of the consumption (investment) good sector, $D_{C,t}$ ($D_{I,t}$) represents consumption (investment) good sector's dividends, B_t denotes bond holdings from time $t-1$ to time t, R_t^f is the risk-free rate and W_t^u represents frictionless wages (i.e. without wage rigidities, see also Uhlig (2007)). The first order conditions of the maximization problem lead to the following expression for the stochastic discount factor (SDF)

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

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

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

---

[5] In an Epstein and Zin (1989) preferences environment, agents care about when uncertainty is resolved. Brown and Kim (2014) show via experiments that subjects prefer early resolution of uncertainty and have RRA greater than the reciprocal of the IES.

Finally, the household's optimal labor allocation leads to

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

2.2 Consumption Good Sector

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

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

where α_C is the capital share, labor $L_{C,t}$ is supplied by the household and A_t is an exogenously specified labor-augmenting productivity subject to both short- and long-run shocks:

$$A_t = e^{a_t}, \qquad a_t = \mu_a + x_{a,t-1} + a_{t-1} + \sigma_a \varepsilon_{a,t}, \qquad x_{a,t} = \rho_a x_{a,t-1} + \sigma_{x,a}\varepsilon_{x,a,t}.$$

The unconditional expected growth rate of productivity is μ_a. Short-run productivity shocks are induced by $\varepsilon_{a,t}$, whereas $\varepsilon_{x,a,t}$ indicates long-run shocks which affect the stochastic component in expected productivity growth $x_{a,t}$. The persistence of long-run productivity shocks is measured by ρ_a. 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 δ_K is the depreciation rate of capital. 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 α_1 and α_2 are chosen such that there are no adjustment costs in the deterministic steady state.

In the spirit of Justiniano et al. (2010) and Papanikolaou (2011) we assume that the marginal efficiency of investment goods is stochastic and governed by the 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 at the relative price $P_{I,t}$. Thus, the total investment cost is given by $Z_{M,t}^{-1}I_{C,t}P_{I,t}$. The marginal efficiency of investment goods is stochastic and follows a strictly stationary AR(1)-process:

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

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

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

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

$$V_{C,0} = \max_{\{K_{C,t+1},I_{C,t},L_{C,t}\}_{t=0}^{t=\infty}} \sum_{t=0}^{\infty} \mathbb{E}_0\left[M_{0,t}D_{C,t}\right], \tag{5}$$

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

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

determines the price of the investment good $P_{I,t}$.

2.3 Investment Good Sector

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

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

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

$$Z_{I,t} = e^{z_{I,t}}, \qquad z_{I,t} = \mu_I + x_{I,t-1} + z_{I,t-1} + \sigma_I \varepsilon_{I,t}, \qquad x_{I,t} = \rho_I x_{I,t-1} + \sigma_{x,I} \varepsilon_{x,I,t}.$$

Thus, as in the consumption good sector, the productivity of the investment good 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 good sector's productivity is denoted by μ_I and ρ_I denotes the persistence of long-run investment shocks. This specification is, for instance, in line with the traditional economic theory of investment hysteresis (see Dixit (1992)). Besides this theoretical justification, we can also provide empirical evidence for the existence of a long-run component in the investment sector.[6] A recently developed database by O'Mahony and Timmer (2009) reports the total factor productivity (TFP) at the sectoral level for the US and several European countries. For US data from 1977 to 2010, estimating the long-run risk component in each sector via a simple standard state-space model gives the following results:[7]

$$\Delta lnTFP_c = 0.009 + x_{c,t-1} + \underbrace{\epsilon^{sr}_{c,t}}_{3.103^{***}[0.000]}$$

$$x_{c,t} = 0.785 \cdot x_{c,t-1} + \underbrace{\epsilon^{lr}_{c,t}}_{0.763^{***}[0.000]}$$

$$\Delta lnTFP_i = 0.001 + x_{i,t-1} + \underbrace{\epsilon^{sr}_{i,t}}_{1.467^{***}[0.000]}$$

$$x_{i,t} = 0.785 \cdot x_{i,t-1} + \underbrace{\epsilon^{lr}_{i,t}}_{1.251^{***}[0.000]} \quad .$$

---

[6] As argued by Müller and Watson (2013), long-run forecasting tends to be econometrically difficult. In this study we provide just a first attempt to detect long-run shocks both in the consumption goods and investment goods sectors by using a standard state-space approach. A rigorous analysis on different methodologies estimating long-run risk components is beyond the scope of the paper. We leave this empirical challenge for future research.

[7] p-values are reported in square brackets. *** indicates significance at the 0.1% level.

Estimations with data from other countries corroborate this finding. Details are reported in Appendix B.

The investment good sector pays wages to the household and produces the demand set by the consumption good sector. Thus, total output $Y_{I,t}$ is sold to the consumption good sector at price $P_{I,t}$. The net profit of the investment good sector is therefore given by

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

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

$$V_{I,0} = \max_{\{L_{I,t}\}_{t=0}^{t=\infty}} \left\{ \sum_{t=0}^{\infty} \mathbb{E}_0 \left[M_{0,t} D_{I,t} \right] \right\}. \tag{6}$$

2.4 Labor Market Frictions

We assume that the labor supply is subject to frictions. In the spirit of Blanchard and Galí (2005) 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 have the following dynamics:

$$W_t = (W_{t-1})^{\xi} (W_t^u)^{1-\xi}$$

W_t^u represents the frictionless wage. Notice that $\xi = 0$ implies the absence of labor market rigidities.

2.5 Market Clearing Conditions

The household supplies labor to the consumption and the investment good 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

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

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

$$C_t = Y_{C,t} = W_t L_t + D_{C,t} + D_{I,t}.$$

The last equality is obtained by assuming that bonds are in zero net supply and the stocks of the consumption and the investment good sector firm are in unit supply, i.e. $B_t \equiv 0$ and $\vartheta_{C,t} \equiv \vartheta_{I,t} \equiv 1$, in the household's budget constraint (2).

3 Benchmark Calibration

We assume that the representative agent has a monthly decision interval. Therefore, we calibrate the model to a monthly frequency. For ease of exposition, however, we subsequently discuss only annualized figures. In our benchmark two-sector production economy nineteen parameters need to be specified: four for preferences, seven relating to the consumer good production sector C, seven modeling the investment good production sector I, and one accounting for the labor market friction. Our parameter choices are summarized in Table 1.

The preference parameters are set in accordance with the recent long-run risk literature. The subjective discount factor is set to an annualized value of 0.97 so as to help the model match the relatively low level of the risk-free rate observed in the data. We set the coefficient of relative risk aversion and elasticity of intertemporal substitution to values of 10 and 1.85, respectively. Similar values can be found in Bansal and Yaron (2004), Croce (2014), Kung and Schmid (2015), among others. Note that we have $\gamma > 1/\psi$, i.e. our parameters also satisfy the constraint reported by Brown and Kim (2014). This implies that agents have a preference for early resolution of uncertainty and thus care about both consumption and utility risk. The consumption share in the utility bundle ν is set to 0.35 such that the steady state supply of labor is one third of the total time endowment of the household.

We calibrate the parameters of the long-run risk processes, $x_{a,t}$ and $x_{I,t}$, in line with the literature on long-run risk. In particular, we fix the persistence of $x_{a,t}$ and $x_{I,t}$ to be $\rho_a = \rho_I = 0.98$ as in Croce (2014). These values imply an annualized persistence of 0.80. As in Croce (2014), we set μ_a and μ_I such that the average annual growth rate is 1.8%, consistent with US data. To keep the long-run component as small as in the data we fix the volatility of the long-run shocks to be a small percentage (7.5%) of the volatility of the short-run shocks (see Bansal and Yaron (2004), Pancrazi (2014)). To this end, we impose $\sigma_{x,a} = 0.075 \cdot \sigma_a$ and $\sigma_{x,I} = 0.075 \cdot \sigma_I$. Finally, $\sigma_a = \sigma_I$ are calibrated to an annualized value of 2% to match the annualized volatility of consumption growth which is around 2%. The annualized depreciation rate of physical capital in the consumption good sector is set to 8.5%. On the production side, as in Papanikolaou (2011), we set the capital shares in consumption good production (α_C) and investment good production (α_I) equal to 0.3 and 0.1, respectively.

The elasticity of the supply curve of capital, τ, is equal to 1.15, a value in line with existing empirical evidence.[8] The parameters related to the marginal efficiency of investment are calibrated as in Justiniano et al. (2010). Therefore, we use $\sigma_M = 12\%$ for the annualized volatility of the shock to the marginal efficiency of investment and assume that the considered shock is moderately persistent with $\rho_M = 0.92$ (see also Furlanetto and Seneca (2014a)).

---

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

Table 1: BENCHMARK (MONTHLY) CALIBRATION. *Notes*: Parameters sources: 1=Papanikolaou (2011), 2=Kung and Schmid (2015), 3=Justiniano et al. (2010), 4=Croce (2014), 5=Uhlig (2007), 6=own calibration.

Parameter	Description	Source	Value
PREFERENCE PARAMETERS			
β	Subjective discount factor	6	0.997
γ	Risk aversion	2/4	10
ψ	Elasticity of intertemporal substitution	2	1.85
ν	Consumption share in utility bundle	6	0.35
PRODUCTION SECTOR C			
Technology parameters			
α_C	Capital share in consumption good production	1	0.3
δ_K	Depreciation rate of physical capital	1	0.085/12
τ	Degree of adjustment costs in investment	1	1.15
TFP parameters			
μ_a	Long-run mean of consumption good sector TFP	4	0.018/12
σ_a	Volatility of short-run shocks to consumption good sector TFP ε_a	6	$0.02/\sqrt{12}$
ρ_a	Autocorrelation of long-run shocks to consumption good sector TFP x_a	4	0.98
$\sigma_{x,a}$	Volatility of long-run shocks to consumption good sector TFP $\varepsilon_{x,a}$	6	$0.075 \cdot \sigma_a$
PRODUCTION SECTOR I			
Technology parameters			
α_I	Capital share in investment good production	1	0.1
TFP parameters			
μ_I	Long-run mean of investment good sector TFP	4	0.018/12
σ_I	Volatility of short-run shocks to investment good sector TFP ε_I	6	$0.02/\sqrt{12}$
ρ_I	Autocorrelation of long-run shocks to investment good sector TFP x_I	4	0.98
$\sigma_{x,I}$	Volatility of long-run shocks to investment good sector TFP $\varepsilon_{x,I}$	6	$0.075 \cdot \sigma_I$
σ_M	Volatility of shocks to investment good efficiency ε_M	3	$0.12/\sqrt{12}$
ρ_M	Autocorrelation of shocks to investment good efficiency Z_M	3	0.92
LABOR MARKET			
ξ	Wage rigidity parameter	5	0.35

4 Quantitative results

To see how the key ingredients of our model lead to the main results, we consider several subcases that allow to analyze their different roles. We start by analyzing the role of the long-run risk component in both sectors (see Table 2, Panel A). To this end, we first solve an economy without any long-run risk (see first column). Then we introduce long-run risk in the consumption sector (second column) and finally we allow for long-run risk both in the consumption and in the investment sector. In all 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.[9] However, the model reproduces the observed co-movements between consumption, labor and output.

Introducing long-run risk in the consumption sector 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. The market equity premium thus increases from 0.62% to 3.41%. Introducing long-run risk in the investment sector further improves the asset pricing quantities, especially the stock return volatility of the investment sector. More precisely, the volatility spread between investment and consumption sector increases from 1.59% to 5.69% and gets closer to the value observed in the data (10.96%). Long-run risk in the investment sector affects only the expected return and volatility differential, but not the expected return of the market portfolio (i.e., the risk premium for the consumption sector decreases slightly and the risk premium for the investment sector increases slightly). This suggests that the long-run risk component of investment shocks is priced by financial markets. Nevertheless, the risk premium is still higher for the consumption sector. This can be explained by differences in the cyclical variation between the two sectors: due to adjustment costs, consumption is more procyclical than investments (i.e. $corr(\Delta c, \Delta y) > corr(\Delta i, \Delta y)$) and therefore riskier from an insurance point of view. In summary, this benchmark calibration shows that the long-run risk component of investment shocks is important to generate realistic differentials between expected returns and between return volatility of consumption and investment sectors.[10] Key macroeconomic quantities remain qualitatively unchanged after the introduction of long-run risk in the investment sector. All calibrations in Panel A fail to explain the correlation between consumption and investment.

In Panel B of table 2 we introduce wage rigidities. The unconditional correlation between consumption and investment changes its sign and becomes positive. The economic mechanism behind this result can be explained from inspecting the impulse-response function of key macroeconomic quantities. These are depicted in Appendix C. Intuitively, wage

---

[9] The market portfolio in all our quantitative results is defined as a claim to the sum of the consumption good sector dividends and the investment good sector dividends.

[10] This is in line with Papanikolaou (2011) who shows that investment shocks generate differences in risk premia due to their heterogeneous impact on different firms.

rigidities change the intertemporal substitution between consumption and labor. This effect is different for the four types of productivity shocks in our model. Consider first the effect of a positive short-run shock in the productivity of the investment sector. In the absence of wage rigidities, such a shock increases the return on investment and gives households an incentive to save more today and postpone consumption (Figure C.3, case $\xi = 0$), which implies that consumption and investments move in opposite directions in response to short-run investment shocks. In contrast, investments decrease in response to long-run shocks in the productivity of the investment sector because of the interaction between the income effect and the substitution effect. Namely, a positive shock to long-run productivity increases the continuation utility. As a result, households react to this long-run shock by reducing investment. This implies that consumption and investments move in the same direction in response to long-run shocks to the productivity of investments.

As is well known from Croce (2014), wealth effect and income effect work in opposite directions after shocks to the TFP process of the consumption sector. As a result, investment and consumption move in the same direction in response to short-run shocks of the consumption TFP while they move in opposite directions in response to long-run shocks of the consumption TFP.

Taken together, the natural question is then the following: can the negative co-movement between consumption and investment induced by short-term investment shocks be compensated by positive co-movement resulting from the other shocks in the economy, namely long-run investment shocks and short-run consumption shocks? We argue that the answer is yes, provided that wage rigidities are included in the model.

The reason for this is that wage rigidities reduce the extent of negative co-movement between consumption and investment in response to short-run investment TFP shocks. To see this, note that wage rigidities reduce the wealth effect on labor supply. More precisely, when the labor market is not fully flexible, not all labor supply reaches the market. As a result labor supply increases by less or even declines in response to short-run investment shocks (see Figure C.2, fourth row). This effect on itself is quantitatively too small to offset the intertemporal substitution between consumption and investment, which implies that consumption and investments still move in opposite directions in response to short-run investment shocks. But the diminished wealth effect on labor supply induced by wage rigidities makes consumption and investment less responsive to short-run investment shocks. As a result, the negative co-movement between consumption and investment in response to investment shocks is reduced. Together with the responses to the other shocks in the economy, the result is an overall positive correlation between consumption and investment as reported in Table 2.

Next, Panel C of Table 2 reports results about the role of adjustment costs. We choose two additional values for the adjustment costs elasticity: $\tau = 0.95$ and $\tau = 3.33$ which impose higher and lower adjustment costs than in the benchmark calibration where $\tau = 1.15$, respectively.[11] The corresponding impulse-response functions are depicted in Figure C.2. In the presence of a lower amount of adjustment costs (i.e. $\tau = 3.33$), the model produces an extremely high investment growth volatility. As a result, the investment-output volatility ratio is equal to 8.46. In addition, due to the dominance of the long-run component, investment becomes less correlated with consumption growth. In particular, the model generates a negative correlation of -0.41 between investment and consumption. This produces a fall in the aggregate equity risk premium, which is now only 2.13%.[12] Differently, in the presence of stronger frictions (i.e. $\tau = 0.95$) consumption and investment growth are more correlated (i.e. $corr(\Delta c, \Delta i) = 0.14$). Consequently, the stock market is riskier and households demand an extra premium (see also Jermann (1998) and Croce (2014)), i.e. the aggregate equity risk premium is 4.01%. Altogether, however, the analysis shows that our asset pricing results hold for a relatively large range of adjustment costs parameter values.

As we have just explained, long-run investment-specific shocks, together with wage rigidities, seem to be a good vehicle to generate a positive co-movement between consumption and investment. In a last step, we now analyze the role of shocks to the

---

[11] We stress that in our benchmark calibration the adjustment costs are set to be smaller than in Jermann (1998) who imposes the elasticity of investment with respect to Tobin's `Q` to be equal to 0.23 (i.e. strong frictions). The introduction of the long-run component in both sectors, however, yields sizable fluctuations in stock prices and investment even with a very mild friction.

[12] Notice that the risk premium between I and C firms (i.e. $\mathbb{E}[R_I] - \mathbb{E}[R_C]$) becomes positive, suggesting that the higher amount of frictions affects mainly the consumption goods sector.

marginal efficiency of investment. The role of these shocks has already been highlighted by Papanikolaou (2011) who shows that, when the marginal efficiency of investment is deterministic, a standard model with i.i.d. TFP shocks cannot explain the basic properties of asset prices such as the equity premium and the return volatility spread unless an unrealistic large volatility of investment shocks is assumed. The last column of Table 2 reports the results for our model when the marginal efficiency of investment is deterministic (i.e. $\sigma_M = 0$). Importantly, the investment growth volatility (relative to the output growth volatility) is not matched correctly in this case. In contrast, the main properties of asset prices and macro quantities are preserved even when we assume a deterministic process for the marginal efficiency of investment and a realistically low volatility of TFP shocks. In other words, the most important economic mechanism that allows our model to generate realistic properties of asset prices is the long-run risk in the TFP processes and not the risk associated with the marginal efficiency of investment as in Papanikolaou (2011).

Table 2: Model versus Data: Asset Prices and Macro Quantities

MODEL	DATA	**A: The Role of LRR**			**B: The Role of Wage Rigidities**				**C: The Role of Adj. Costs**			**D: Special Case**
		$\sigma_{x,a} = 0$ $\sigma_{x,I} = 0$ $\xi = 0$	$\sigma_{x,a} > 0$ $\sigma_{x,I} = 0$ $\xi = 0$	$\sigma_{x,a} > 0$ $\sigma_{x,I} > 0$ $\xi = 0$	LRR $\xi = 0.20$	LRR $\xi = 0.35$	LRR $\xi = 0.50$	$\sigma_{x,I} = 0$ $\xi = 0.35$	LRR $\xi = 0.35$ $\tau = 0.95$	LRR $\xi = 0.35$ $\tau = 1.15$	LRR $\xi = 0.35$ $\tau = 3.33$	LRR $\sigma_M = 0$
ASSET PRICES												
$\mathbb{E}[R_M - R_f]$ (%)	4.89	0.62	3.41	3.41	3.47	**3.54**	3.63	3.54	4.01	**3.54**	2.13	3.54
$\sigma[R_M]$ (%)	17.92	2.07	3.10	3.26	3.46	**3.49**	4.15	3.61	3.78	**3.49**	2.90	3.65
$\mathbb{E}[R_I] - \mathbb{E}[R_C]$ (%)	-1.41	-0.56	-0.85	-0.41	-0.41	**-0.41**	-0.41	-0.85	-0.96	**-0.41**	0.91	-0.41
$\sigma[R_I] - \sigma[R_C]$ (%)	10.96	0.14	1.59	5.69	5.54	**5.39**	4.79	1.19	4.92	**5.39**	6.27	5.52
$\mathbb{E}[R_f]$ (%)	2.90	3.71	2.61	2.61	2.57	**2.53**	2.48	2.53	2.53	**2.53**	2.48	2.53
$\sigma[R_f]$ (%)	3.00	0.60	0.64	0.65	1.04	**1.48**	2.03	1.47	1.44	**1.48**	1.49	1.47
MACRO QUANT												
$\sigma(\Delta c)$	1.95	1.40	1.52	1.64	1.77	**1.95**	2.36	1.87	1.91	**1.95**	2.25	2.02
$\sigma(\Delta i)/\sigma(\Delta y)$	4.49	9.12	8.63	8.61	7.65	**6.36**	5.07	6.32	5.67	**6.36**	8.46	1.57
$\sigma(\Delta y)/\sigma(\Delta c)$	1.41	1.10	1.08	1.10	1.11	**1.07**	1.09	1.09	1.08	**1.07**	1.60	1.09
$\sigma(\Delta y)/\sigma(\Delta l)$	1.29	4.94	3.48	3.43	2.12	**1.46**	1.13	1.48	1.45	**1.46**	1.00	1.46
$\sigma(\Delta l)$	2.52	0.31	0.46	0.48	0.89	**1.47**	2.36	1.48	1.48	**1.47**	3.64	1.48
$corr(\Delta c, \Delta i)$	0.39	-0.03	-0.09	-0.01	-0.04	**0.01**	0.12	0.04	0.11	**0.01**	-0.41	0.43
$corr(\Delta c, \Delta y)$	0.84	0.97	0.94	0.92	0.95	**0.96**	0.98	0.97	0.97	**0.96**	0.15	0.98
$corr(\Delta c, \Delta l)$	0.41	0.25	0.04	0.08	0.43	**0.65**	0.79	0.64	0.66	**0.65**	-0.18	0.70
$corr(\Delta i, \Delta l)$	0.83	0.92	0.68	0.74	0.46	**0.38**	0.31	0.33	0.13	**0.38**	0.93	0.67
$corr(\Delta i, \Delta y)$	0.67	0.18	0.18	0.17	0.14	**0.19**	0.29	0.23	0.08	**0.19**	0.81	0.55

Notes: LRR indicates the presence of long-run risk in both the consumption and investment sector. The aggregate market risk premium, $\mathbb{E}[R_M - R_f]$, is levered as in Boldrin et al. (2001). Empirical moments are from Papanikolaou (2011) except for $\sigma(\Delta i)/\sigma(\Delta y)$ and $\sigma(\Delta y)/\sigma(\Delta c)$ which are from Croce (2014). Moments are obtained from repetitions of small-sample simulations. The columns in bold font represent the benchmark calibration whose parameters are reported in Table 1.

5 Conclusion

The recent asset pricing and macroeconomic literature has proposed investment shocks as the main driver of asset pricing and macroeconomic dynamics. However, as shown by Papanikolaou (2011) shocks to the total factor productivity of the investment sector cannot account for the high equity premium and the return volatility differential between the consumption and the investment sector unless coupled with shocks to the marginal efficiency of investments. In this paper we argue that the shocks to the marginal efficiency of investments can be replaced by long-run risk in the total factor productivity of the investment sector without affecting the ability of the model to explain key features of asset prices. Our production-based asset pricing model with long-run productivity risk, capital adjustment costs and wage rigidities replicates the equity premium, the stock return volatility differential between the consumption and the investment sector, the positive co-movement between consumption and investment growth and the high volatility of investment growth. Our paper thus bridges an important gap in the literature by focusing on the joint implications of investment shocks on the dynamics of financial and macroeconomic quantities.

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 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, we suggest that investment shocks alter the perception regarding long-term productivity and that this effect, which goes above and beyond the effect of investment shocks on the cost of producing new capital, is important for explaining the risk-return differential between consumption and investment sectors. This explanation is not only in line with the theory of investment hysteresis, but is also corroborated by empirical estimates of sectoral productivity processes. We thus think that long-run investment shocks are a very natural modeling choice given the empirical evidence.

Despite long-run productivity risk being intuitive and economically appealing, it has difficulties to account for the joint behavior of macroeconomic co-movements and asset pricing moments. In particular, consumption and investment tend to move in opposite directions in reaction to short-run investment shocks. This effect is quantitatively important and cannot be compensated by the other shocks in the economy. As a result, the unconditional correlation between consumption and investment is negative, in contrast to the empirical evidence. However, our analysis shows that moderate wage rigidities make consumption and investment less responsive to short-run investment shocks. This implies that, in the presence of wage rigidities, the negative co-movement between consumption and investment induced by short-run investment shocks can be compensated by positive co-movement resulting from long-run investment shocks, and the unconditional correlation between consumption and investment becomes positive, consistent with empirical evidence. These results suggest that investment shocks contribute a great deal to explaining the dynamics of asset prices, but need to be coupled with nominal rigidities (or other sources of market imperfections) to generate realistic macroeconomic co-movements.

References

Abel, A., 1980. Empirical Investment Equations: An Integrative Framework. Carnegie-Rochester Conference Series on Public Policy .

Bansal, R., Yaron, A., 2004. Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles. Journal of Finance 59, 1481–1509.

Blanchard, O., Galí, J., 2005. Real Wage Rigidities and the New Keynesian Model. NBER Working Paper No. 11806 .

Boldrin, M., Christiano, L. J., Fisher, J. D., 2001. Habit Persistence, Asset Returns and the Business Cycle. American Economic Review 91, 149–166.

Brown, A. L., Kim, H., 2014. Do Individuals Have Preferences Used in Macro-Finance Models? An Experimental Investigation. Management Science 60, 939–958.

Caldara, D., Fernández-Villaverde, J., Rubio-Ramírez, J., Yao, W., 2012. Computing DSGE Models with Recursive Preferences and Stochastic Volatility. Review of Economic Dynamics 15, 188–206.

Colacito, R., Croce, M. M., 2013. International Asset Pricing with Recursive Preferences. Journal of Finance 68, 2651–2686.

Croce, M. M., 2014. Long-Run Productivity Risk: A New Hope for Production-Based Asset Pricing? Journal of Monetary Economics 66, 13–31.

Dixit, A., 1992. Investment and Hysteresis. Journal of Economic Perspectives 6, 107–132.

Eberly, J., 1997. International Evidence on investment and Fundamentals. European Economic Review 41, 1055–1078.

Epstein, L., Zin, S., 1989. Substitution, Risk Aversion, and the Temporal Behavior of Consumption Growth and Asset Returns I: A Theoretical Framework. Econometrica 57, 937–969.

Furlanetto, F., Natvik, G. J., Seneca, M., 2013. Investment Shocks and Macroeconomic co-movement. Journal of Macroeconomics 37, 208–216.

Furlanetto, F., Seneca, M., 2014a. Investment Shocks and Consumption. European Economic Review 66, 111–126.

Furlanetto, F., Seneca, M., 2014b. New Perspectives on Depreciation Shocks as a source of Business Cycle Fluctuations. Macroeconomic Dynamics 18, 1209–1233.

Greenwood, J., Hercowitz, Z., Krusell, P., 2000. The Role of Investment-Specific Technological Change in the Business Cycle. European Economic Review 44, 91–115.

Jermann, U. J., 1998. Asset Pricing in Production Economies. Journal of Monetary Economics 41, 257–275.

Justiniano, A., Primiceri, G. E., Tambalotti, A., 2010. Investment Shocks and Business Cycles. Journal of Monetary Economics 57, 132–145.

Justiniano, A., Primiceri, G. E., Tambalotti, A., 2011. Investment Shocks and the Relative Price of Investments. Review of Economic Dynamics 14, 102–121.

Khan, H., Tsoukalas, J., 2011. Investment Shocks and the Comovement Problem. Journal of Economic Dynamics and Control 35, 115–130.

Kogan, L., Papanikolaou, D., 2014. Growth Opportunities, Technology Shocks, and Asset Prices. Journal of Finance 69, 675–718.

Kung, H., Schmid, L., 2015. Innovation, Growth, and Asset Prices. Journal of Finance Forthcoming.

Müller, U. K., Watson, M. W., 2013. Measuring Uncertainty about Long-Run Predictions. Working Paper .

O'Mahony, M., Timmer, M., 2009. Output, Input and Productivity Measures at the Industry Level: the EU KLEMS Database. Economic Journal 119, 374–403.

Pancrazi, R., 2014. How Beneficial Was the Great Moderation After All? Journal of Economic Dynamics and Control 46, 73–90.

Papanikolaou, D., 2011. Investment Shocks and Asset Prices. Journal of Political Economy 119, 639–685.

Uhlig, H., 2007. Explaining Asset Prices with External Habits and Wage Rigidities in a DSGE Model. American Economic Review 97, 239–243.

A Equilibrium

The equilibrium allocation in this economy consists of (i) time paths of consumption level, total labor hours, labor hours supplied to the consumption good sector and investment good sector, and utility flow level $\{C_t, L_t, L_{C,t}, L_{I,t}, v_t\}_{t=0}^{t=\infty}$, (ii) time paths of consumption good output, physical capital, investment and level of new capital created $\{Y_{C,t}, K_{C,t}, I_{C,t}, G_t\}_{t=0}^{t=\infty}$, (iii) time paths of investment good output and investment good price $\{Y_{I,t}, P_{I,t}\}_{t=0}^{t=\infty}$, (iv) time paths of dividends and cum-dividend stock prices for both the consumption and investment good sector $\{D_{C,t}, V_{C,t}, D_{I,t}, V_{I,t}\}_{t=0}^{t=\infty}$ and (v) time paths of the pricing kernel in consumption and utility flow units, the wealth-utility ratio, the return on wealth and the risk-free rate $\left\{M_{t,t+1}, M_{t,t+1}^{(v)}, u_t, R_t^W, R_{f,t}\right\}_{t=0}^{t=\infty}$, such that (a) the representative household maximizes lifetime utility (1), (b) the consumption good sector maximizes its value (5) and (c) the investment good sector maximizes its value (6).

This implies that the equilibrium is determined by a system of 23 equations for 23 variables, v_t, R_t^W, C_t, L_t, $L_{C,t}$, $L_{I,t}$, W_t^u, W_t, $Y_{C,t}$, $Y_{I,t}$, $K_{C,t}$, $I_{C,t}$, $P_{I,t}$, λ_t, $M_{t,t+1}$, $M_{t,t+1}^{(v)}$, u_t, $D_{C,t}$, $V_{C,t}$, $D_{I,t}$, $V_{I,t}$, G_t and $R_{f,t}$, given the endogenous state variable $K_{C,t}$ and five exogenous state variables $A_t, Z_{I,t}, Z_{M,t}, x_{a,t}, x_{I,t}$. The equations to be solved can be grouped as follows:

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

$$
\begin{aligned}
W_t^u &= \frac{1-\nu}{\nu}\left(\frac{C_t}{1-L_t}\right) \\
W_t &= (W_{t-1})^{\xi}(W_t^u)^{1-\xi} \\
v_t &= C_t^{\nu}\left(A_{t-1}(1-L_t)\right)^{1-\nu} \\
u_t &= 1+\mathbb{E}_t\left[M_{t,t+1}^{(v)}u_{t+1}\frac{v_{t+1}}{v_t}\right] \\
R_t^W &= \frac{u_t+\frac{v_t}{v_{t-1}}}{u_{t-1}-1} \\
M_{t,t+1} &= \beta\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(\frac{v_{t+1}}{v_t}\right)^{1-\frac{1}{\psi}}\left(\frac{U_{t+1}}{[\mathbb{E}_tU_{t+1}^{1-\gamma}]^{\frac{1}{1-\gamma}}}\right)^{\frac{1}{\psi}-\gamma} = \beta^{\theta}\left(\frac{v_{t+1}}{v_t}\right)^{1-\frac{\theta}{\psi}}\left(\frac{C_{t+1}}{C_t}\right)^{-1}\left(R_{t+1}^W\right)^{\theta-1} \\
M_{t,t+1}^{(v)} &= \beta^{\theta}\left(\frac{v_{t+1}}{v_t}\right)^{-\frac{\theta}{\psi}}\left(R_{t+1}^W\right)^{\theta-1}
\end{aligned}
$$

$$\frac{1}{R_t^f} = \mathbb{E}_t[M_{t,t+1}].$$

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

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

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

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

4. Market clearing conditions

$$\begin{aligned}
L_t &= L_{C,t} + L_{I,t} \\
Y_{I,t} &= Z_{M,t}^{-1}I_{C,t}
\end{aligned}$$

$$C_t = Y_{C,t} = W_t L_t + D_{C,t} + D_{I,t}.$$

5. Evolution of the five exogenous state variables

$$\begin{aligned}
\log(A_t) &= \mu_a + x_{a,t-1} + \log(A_{t-1}) + \sigma_a \varepsilon_{a,t} \\
x_{a,t} &= \rho_a x_{a,t-1} + \sigma_{x,a} \varepsilon_{x,a,t} \\
\log(Z_{I,t}) &= \mu_I + x_{I,t-1} + \log(Z_{I,t-1}) + \sigma_I \varepsilon_{I,t} \\
x_{I,t} &= \rho_I x_{I,t-1} + \sigma_{x,I} \varepsilon_{x,I,t} \\
Z_{M,t} &= \rho_M Z_{M,t-1} + \sigma_M \varepsilon_{M,t}.
\end{aligned}$$

We solve the model in dynare++ 4.2.1 using a second-order approximation.

B Estimating sectoral productivity shocks

Sectoral TFP are retrieved from the EU KLEMS database. Data are available for 34 industries, which are classified following the new international ISIC Revision 4 industry classification (consistent with the European NACE 2 industry classification). Industry-level data are provided for the following countries: Austria, Belgium, Finland, France, Germany, Italy, Japan, Netherlands, Spain, Sweden, UK and United States. Data are on an annual basis and cover the period 1977-2010. A summary of the construction of the EU KLEMS database can be found in O'Mahony and Timmer (2009).

Using the EU KLEMS database, we proxy the consumption sector productivity, TFP_C, and the investment sector productivity, TFP_I, in the following way:

- TFP_C: TOTAL MANUFACTURING, ELECTRICITY, GAS AND WATER SUPPLY, WHOLESALE AND RETAIL TRADE (cross-sector average)
- TFP_I: CONSTRUCTION, FINANCIAL AND INSURANCE ACTIVITIES, INFORMATION AND COMMUNICATION, TRANSPORTATION (cross-sector average)

The estimations of the short-run and long-run shocks in each sector SS are then carried out via a state-space model which takes the following standard form:

$$\Delta lnTFP_S = \hat{\mu}_S + x_{S,t-1} + \epsilon^{sr}_{S,t}$$

$$x_{S,t} = \bar{\rho}_S z_{S,t-1} + \epsilon^{lr}_{S,t}.$$

Estimation results for different countries are reported in Table B.1.

Table B.1: Cross-Sector Short-Run and Long-Run Shocks. *Notes*: $\hat{\mu}_C$ and $\hat{\mu}_I$ represent the estimated mean of the TFP growth in sector C and I, respectively. The persistence parameter of the long-run component in both sectors is assumed to be fixed. EU represents the Eurozone countries for which growth accounting could be performed, namely: AUT, BEL, ESP, FIN, FRA, GER, ITA and NLD (Source: EU KLEMS Growth and Productivity Accounts: November 2009 Release, updated March 2011). p-values are reported in square brackets. *** indicates significance at 0.1% level.

	CONSUMPTION GOODS SECTOR				INVESTMENT GOODS SECTOR			
Parameter	$\hat{\mu}_C$	$\bar{\rho}_C$	$\sigma(\epsilon^{sr}_C)$	$\sigma(\epsilon^{lr}_C)$	$\hat{\mu}_I$	$\bar{\rho}_I$	$\sigma(\epsilon^{sr}_I)$	$\sigma(\epsilon^{lr}_I)$
BELGIUM	0.000	0.725	1.677***	0.000	0.009	0.725	2.768***	0.000
(1980-2009)			[0.000]	[0.999]			[0.000]	[0.999]
FRANCE	0.013	0.785	0.548***	1.827***	0.010	0.785	1.612***	0.601***
(1980-2009)			[0.001]	[0.000]			[0.000]	[0.000]
GERMANY	0.011	0.725	2.497***	0.000	0.01	0.725	2.458***	0.000
(1970-2009)			[0.000]	[0.999]			[0.000]	[0.999]
ITALY	-0.003	0.725	3.931***	0.000	-0.003	0.785	1.874***	0.725***
(1971-2009)			[0.000]	[0.998]			[0.000]	[0.000]
JAPAN	0.018	0.785	0.000	3.047***	0.002	0.785	2.421***	0.691***
(1973-2009)			[0.998]	[0.000]			[0.000]	[0.000]
SPAIN	0.005	0.785	1.404***	0.289***	0.002	0.785	1.639***	0.929***
(1980-2009)			[0.000]	[0.000]			[0.000]	[0.000]
NLD	0.0133	0.785	2.097***	0.000	0.001	0.785	2.513***	0.542***
(1979-2009)			[0.000]	[0.999]			[0.000]	[0.001]
UK	0.009	0.785	2.502***	0.905***	0.004	0.785	2.557***	0.000
(1972-2009)			[0.000]	[0.000]			[0.000]	[0.997]
US	0.009	0.785	3.103***	0.763***	0.000	0.785	1.467***	1.251***
(1977-2009)			[0.000]	[0.000]			[0.000]	[0.000]
EU	0.013	0.785	1.294***	0.000	0.006	0.785	0.650***	0.226***
(1981-2007)			[0.000]	[0.999]			[0.000]	[0.000]

C Impulse-Response Functions

C.1 Investment-Specific Shocks

Figure C.1: Impulse-Responses to Investment-Specific Shocks: The Role of ξ

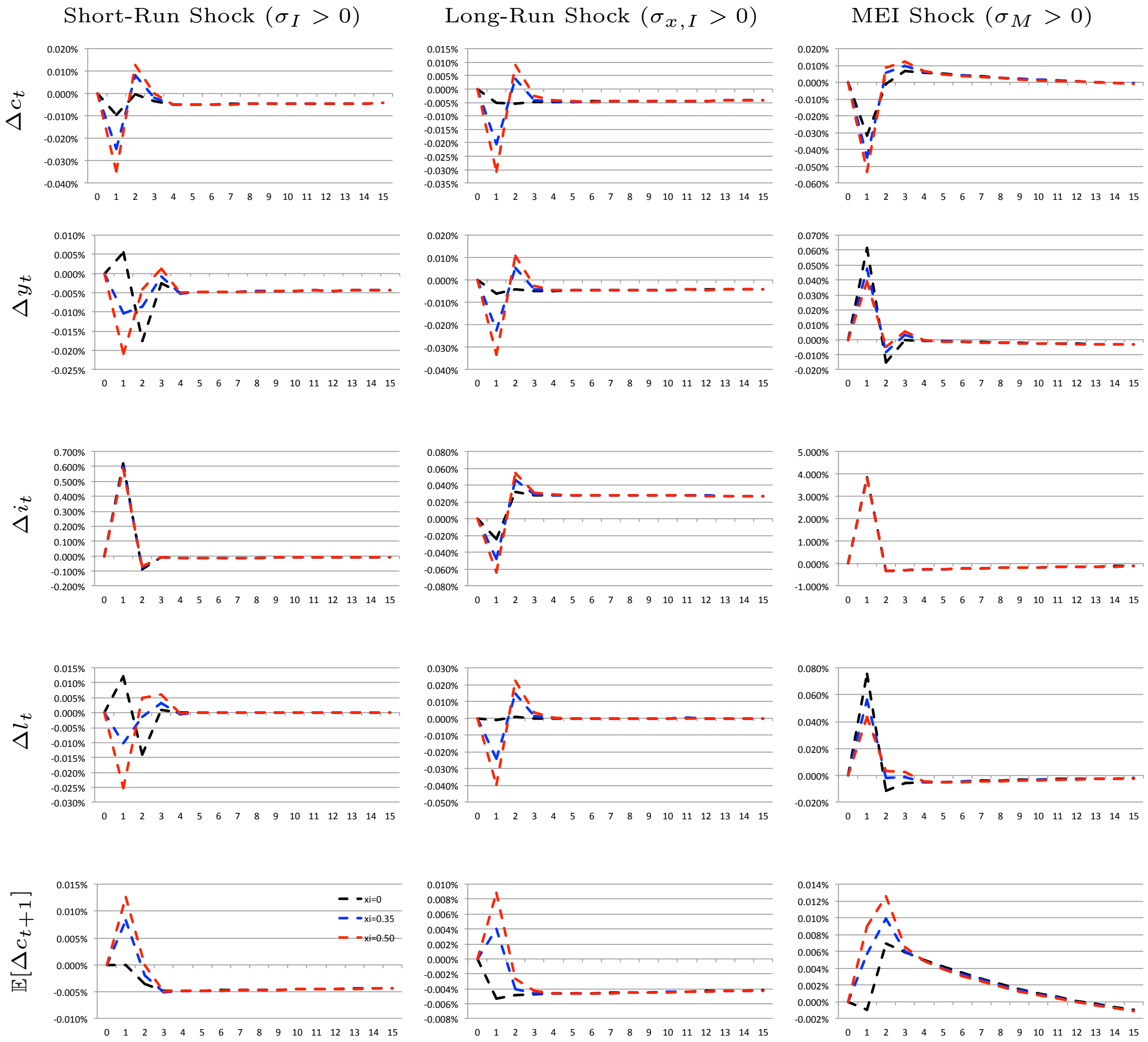
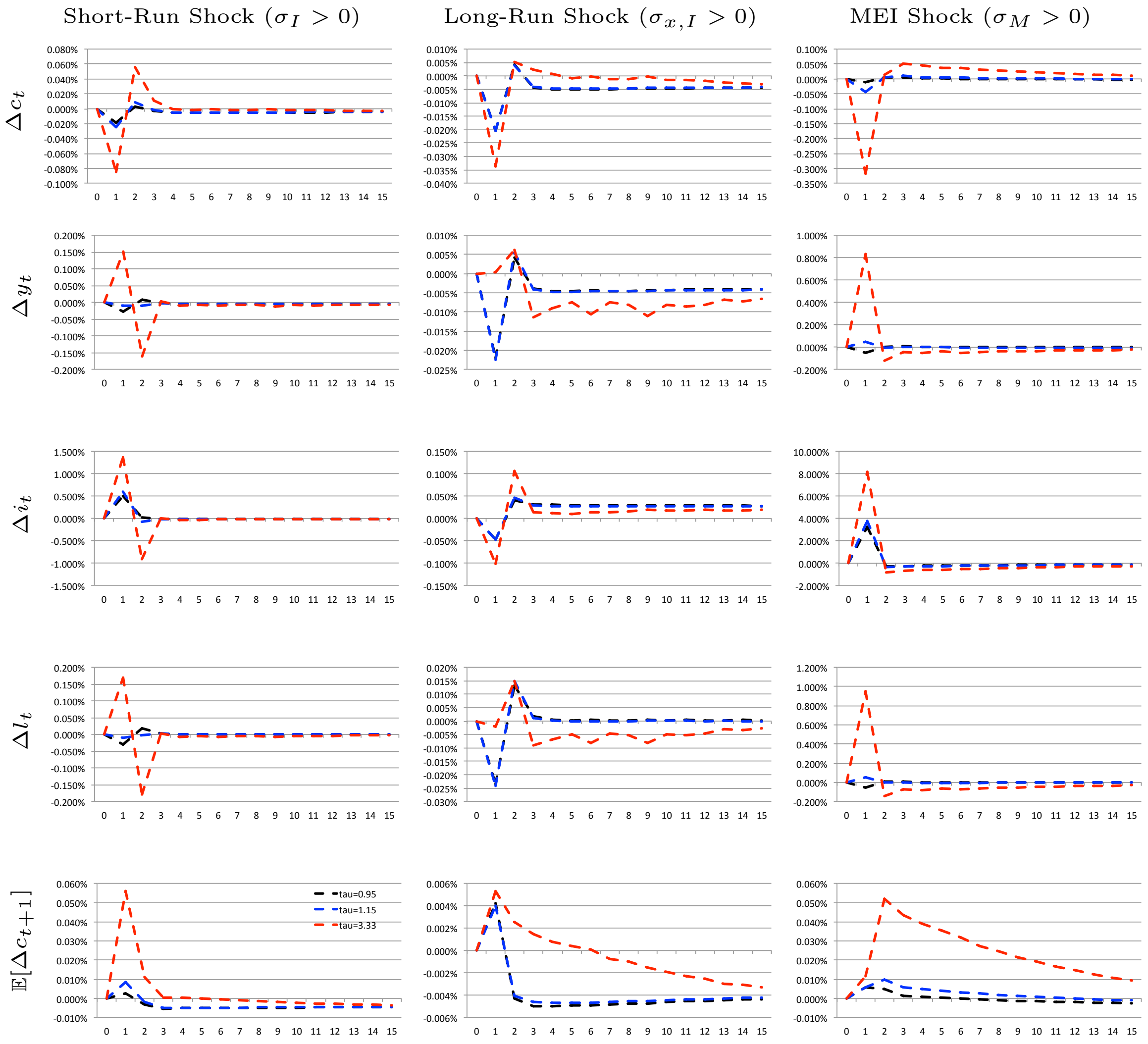


Figure C.2: IMPULSE-RESPONSES TO INVESTMENT-SPECIFIC SHOCKS: THE ROLE OF τ



Short-Run Shock ($\sigma_I > 0$) Long-Run Shock ($\sigma_{x,I} > 0$) MEI Shock ($\sigma_M > 0$)

C.2 Consumption Sector TFP Shocks

Figure C.3: Impulse-Responses to Consumption Sector Shocks: The Role of ξ

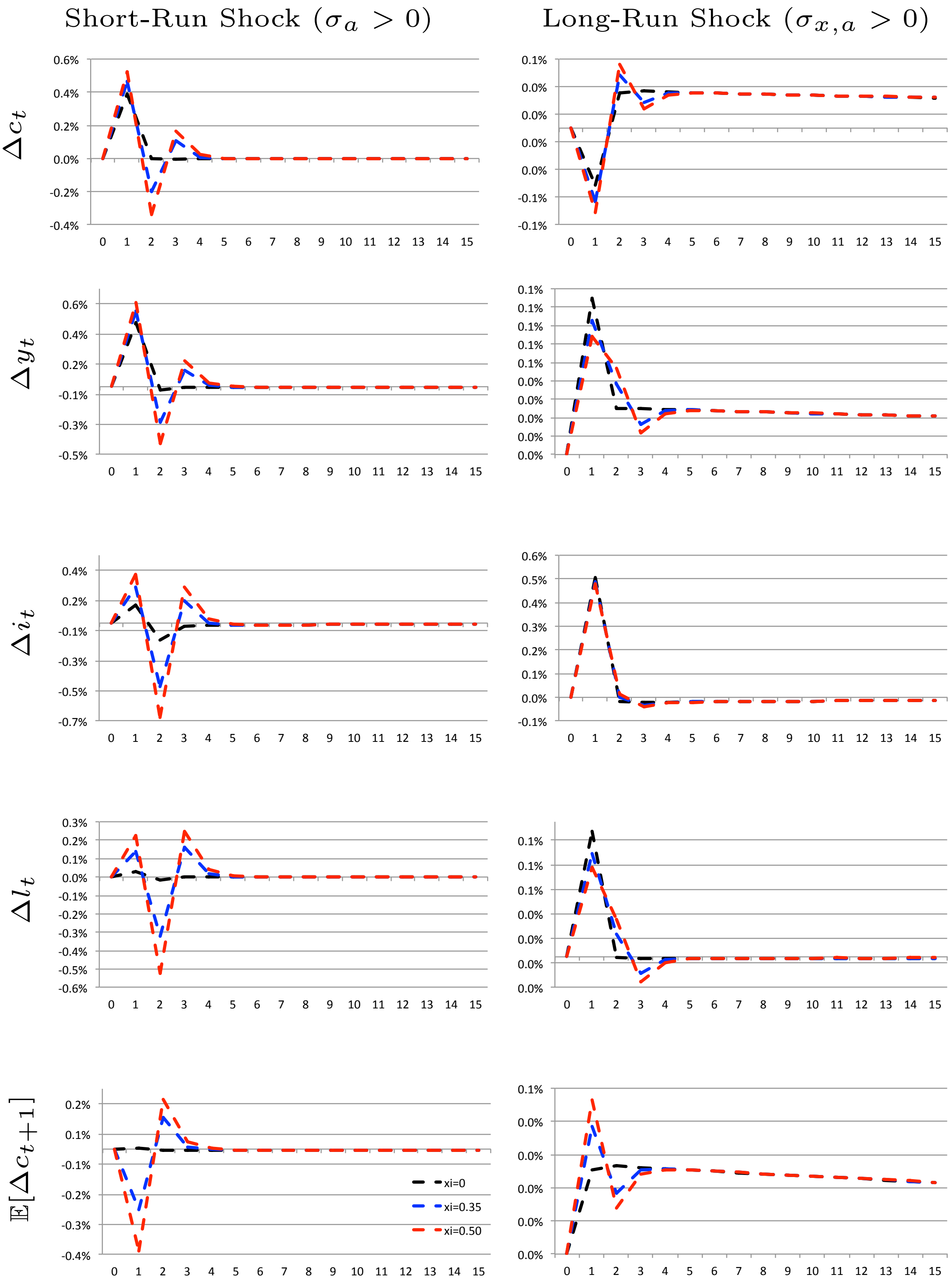


Figure C.4: Impulse-Responses to Consumption Sector Shocks: The Role of τ