A Tale of Two Volatilities:
Sectoral Uncertainty, Growth, and Asset Prices[☆]

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Abstract

What is the impact of higher technological volatility on asset prices and macroeconomic aggregates? I find the answer hinges on its sectoral origin. Volatility that originates from the consumption (investment) sector drops (raises) macroeconomic growth rates and stock prices. Moreover, consumption (investment) sector's technological volatility has a positive (negative) market price of risk. I show that a quantitative two-sector DSGE model that features monopolistic power for firms and sticky prices, as well as early resolution of uncertainty, can explain the differential impact of sectoral volatilities on real and financial variables. In all, the sectoral decomposition of volatility can overturn the typical negative relation between aggregate volatility and economic activity.

Keywords: volatility, investment shocks, asset pricing, economic growth
JEL: C58, D80, E23, G12

[☆] This paper is based on the second chapter of my PhD dissertation at the Wharton School. I thank the helpful comments of Amir Yaron, Ivan Shaliastovich, João Gomes, Itay Goldstein and seminar participants at the Wharton School, University of North Carolina at Chapel Hill, Ohio State University, Northwestern University, Boston College, University of Minnesota, Board of Governors of the Federal Reserve System, University of Utah, Emory University, University of Rochester, Bocconi University, University of Southern California, Carnegie-Mellon University, and MFA Meeting 2017.

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1. Introduction

It is a common notion that uncertainty played an important role in deepening the recent Great Recession and inhibiting economic recovery. Consequently, there has been a growing research effort in macroeconomics and in finance to understand the implications of volatility shocks. Macroeconomic studies typically show that increased volatility is associated with lower investment and output. In asset pricing, most studies argue that volatility drops asset-valuation ratios and raise risk premia.

In this study, I find that contrary to the typical view, volatility is not necessarily contractionary. I show that whether volatility is associated with good or bad economic times depends both empirically and theoretically on its sectoral origin. Specifically, I split the economy into two broad sectors: the consumption sector and the investment sector. I study the pricing and the macroeconomic implications of level (first-moment) shocks and volatility (second-moment) shocks in these two sectors.

I show a novel empirical finding: fluctuations in the volatilities of the investment sector and the consumption sector have opposite impact on the real and the financial economy. By volatility in this paper, I refer to the time-varying volatility of technology shocks (which I also refer to as uncertainty about productivity, or TFP volatility). The market's fear of uncertainty is well justified when the productivity of the consumption sector is more uncertain. Technological volatility of the consumption sector depresses stock prices and aggregate investment. By contrast, and opposite to the traditional view, uncertainty about the productivity of investment good producers boosts aggregate cash flows and raises equity valuations. Moreover, the investment sector's volatility helps explain return spreads based on momentum and Tobin's Q, beyond the ability of sectoral first-moment innovations.

I explain the empirical findings using a quantitative general equilibrium production-based model. The model features two sectors, consumption and investment, whose production is subject to sectoral TFP shocks with time-varying volatility. While a standard perfect-competition model fails to fully explain the data, I show that a model that features monopolistic power for firms and sticky prices, as well as early resolution of uncertainty under Epstein and Zin (1989) and Weil (1989) preferences, is capable of explaining the differential impact of sectoral volatilities on real and financial variables.

A starting point of my study is that uncertainty takes many different forms. These can yield opposite economic implications. Focusing on the consumption versus the investment sector's TFP volatility, stems from a voluminous macro finance literature that divides the economy according to these two classifications. This literature stresses the importance of innovations to the level of investment technology (*first-moment* shocks) for the business cycle, the equity premium, and certain return spreads.[1] To the best of my knowledge, my study is the first to examine the differential role of consumption and investment TFP volatility (*second-moment* shocks) for prices and growth.

[1]More precisely, many of these studies discuss investment-specific technological shocks, or IST. IST shocks refer to the log-difference between investment and consumption TFP level innovations. With some contrast, in my study I examine the total Solow residual of both sectors. Though the approaches are related, I choose to focus on total TFPs and their volatilities, as it allows me to directly map the empirical measures to the model of this paper (the primitives in my model are Hicks-neutral sectoral TFPs and their volatilities).

The focus on the TFP volatility of the two sectors can be motivated economically. The investment sector is producing new capital goods. As a result, investment TFP shocks have endogenously a prolonged effect on the economy, as they affect the capital stock that is slowly depreciating. By contrast, the consumption sector takes the preproduced capital and assembles it to final (perishable) goods. As such, consumption TFP shocks have a more transitory effect, as they rescale the flow of consumption. This distinction between an effect on stock versus flow can suggest that when volatility rises in one of these two sectors, the economy may respond differentially. Interestingly, I find results along this line of thought.

Empirically, using measures of sectoral volatility shocks, I show four novel stylized facts:[2] (1) consumption (investment) sector's TFP volatility is associated with lower (higher) growth of investment, output, and consumption; (2) cross-sectional return-based evidence suggests that consumption (investment) TFP volatility raises (drops) the investor's marginal utility (i.e., negative and positive market prices of risk for consumption and investment TFP volatilities, respectively); (3) by and large, firms' beta to consumption (investment) TFP volatility is negative (positive); (4) investment TFP volatility is important for the pricing of cross-sectional spreads (e.g., the momentum spread).

Using a quantitative dynamic stochastic general equilibrium (DSGE) model, my paper explains the opposite impact of sectoral volatilities on aggregate cash flows and aggregate valuations. The model features two sectors: consumption and investment. The output of the consumption sector is a final good that is sold to the household, and it is subject to a consumption TFP shock. The output of the investment sector is the economy's aggregate investment, and it is subject to an investment TFP shock. This output flows to both consumption firms and investment firms that wish to invest.

In general, when volatility rises, two opposite forces are at work: a (negative) income effect, which boosts investment, and a (positive) substitution effect, which suppresses investment. A consumption TFP innovation is a multiplicative shock that only alters consumption's scale and thus has a transient impact. By contrast, an investment TFP innovation influences the multi-period stock of aggregate capital and thus has a long-term impact. Consequently, consumption TFP volatility resembles only short-run capital risk, while investment TFP volatility resembles more income risk that affects the entire trajectory of future growth. This can explain why the substitution effect would dominate for consumption TFP volatility, while the income effect would dominate for investment TFP volatility.

When TFP volatility of the investment sector rises, it implies that in future periods the probability of having suboptimal amount of investment goods rises. In this case, the household has a strong incentive to invest more and consume less, due to "precautionary saving." Investing more, and shifting resources to the investment sector, ensures higher aggregate capital in the future. Capital can be used for both consumption and investment production. Hence, it acts as a buffer of savings. If a bad investment TFP shock is realized, the buffer can be used to smooth consumption.

By contrast, I show that under early resolution of uncertainty preferences, more consumption TFP volatility makes the household more impatient. This triggers more consumption and less investment. Intuitively, under early resolution

[2] I measure the TFP volatility of the consumption and investment sectors via the predictable component of sectoral TFP realized variances. For more details, see discussion in Section 3.2.

of uncertainty case, the agent dislikes uncertainty. To minimize her exposure to volatility buildup in the future, she shifts her consumption profile as much as possible to the present, which implies lower investment.

The former discussion demonstrates that consistent with the data, a model with perfect competition leads investment expenditures to rise (drop) with investment (consumption) TFP volatility. However, because consumption and investment are substitutes, with perfectly competitive firms, a sectoral TFP volatility shock would cause consumption and aggregate investment to counterfactually diverge. The model therefore features time-varying markups, which builds upon monopolistic competition and sticky prices. Time-varying markups make consumption and aggregate investment comove in response to a sectoral volatility shock, consistent with the data.[3] Consequently, sticky prices play an important part in explaining macroeconomic facts and volatility risk premia.

As is common in production models, aggregate investment and stock prices comove. Consequently, the two sectoral TFP volatilities have opposite impact on stock prices. In particular, since higher investment TFP volatility increases investment, it increases the demand for capital goods and also their relative price. As a result, the value of firms' capital rises, and stock prices appreciate. This implies, as in the data, that firms have a positive beta to investment TFP volatility. The opposite logic applies to consumption TFP volatility, and implies negative betas to consumption TFP volatility, consistent with the data.

The behavior of the market prices of risk is derived from consumption dynamics and preferences. Consumption TFP volatility depresses aggregate consumption and generates a more volatile consumption profile. Both effects, under early resolution of uncertainty, imply a negative market price of risk. Investment TFP volatility also increases consumption's volatility. However, this volatility has a prolonged impact on the economy through capital buildup. This capital buildup leads to a rise in long-run consumption. Quantitatively, the latter channel can dominate the first, implying a positive market price of risk for investment TFP volatility, as in the data.

In all, the market price of risk and the market portfolio's exposure to consumption (investment) TFP volatility are both negative (positive). Given this model outcome and given that the volatilities are persistent under Epstein and Zin (1989) preferences, the contribution of both sectoral volatilities to the equity premium is positive and quantitatively large (similar to the long-run risks framework of Bansal and Yaron, 2004). This is a nonstandard feature in general equilibrium production models.

On the macroeconomic front, this paper shows that one should not necessarily be concerned of higher volatility if it originates from investment firms, to the extent that it is empirically associated with improvements of growth and prices. On the asset pricing front, my work highlights that sectoral volatility shocks, in particular in the investment sector, can go beyond first-moment innovations in explaining return spreads.

The rest of this paper is organized as follows. In Section 2, I review related literature. Section 3 shows the novel empirical facts regarding sectoral TFP volatilities. In Section 4, I present the general equilibrium model and discuss

[3]Without markups (perfect competition), the divergence implies that consumption TFP volatility would counterfactually boost consumption, not only contemporaneously but also in the future. Counterfactual consumption behavior could also adversely affect the magnitude of the market price of consumption TFP volatility risk. With time-varying markups, comovement suggests that consumption TFP volatility drops both consumption and investment. See related discussion on the role of markups for comovement in Fernández-Villaverde et al. (2015) and Basu and Bundick (2017).

its intuition. Section 5 presents the quantitative results. Section 6 provides concluding remarks.

2. Related literature

The paper relates to two main strands of literature. First, the paper relates to a growing literature discussing the implications of volatility shocks for macroeconomic growth and asset prices. I contribute to this literature by documenting novel channels, through which fundamental volatilities can interact both positively and negatively with macro aggregates and prices. Volatility in this study refers to the conditional volatility of shocks to TFP.

Empirically, the typical relation between volatility and the macroeconomy is negative. This link is shown in Ramey and Ramey (1995), Martin and Rogers (2000), and more recently by Engel and Rangel (2008), Bloom (2009), Baker and Bloom (2013), and Kim and Kung (2015). Fewer empirical works, show a positive impact of volatility, such as Kormendi and Meguire (1985) on output and Stein and Stone (2013) on research and development (R&D) expenditures.

From a theoretical perspective, there are more mixed results regarding the impact of volatility on investment. On one hand, some studies highlight a negative impact on investment. The works of McDonald and Siegel (1986), Dixit and Pindyck (1994), and recently Bloom (2009) use real option effects to explain why volatility suppresses investment and hiring. The work of Fernandez-Villaverde et al. (2011) discusses uncertainty in an open economy, showing that volatility lowers domestic investment. Other papers argue that volatility increases the cost of capital, or credit spreads, making investment more costly (see, e.g., Christiano, Motto, and Rostagno, 2014; Gilchrist, Sim, and Zakrajsek, 2014; and Arellano, Bai, and Kehoe, 2018). Fernández-Villaverde et al. (2015) and Basu and Bundick (2017) rely on sticky prices to show that both consumption and investment drop in response to volatility shocks. On the other hand, other studies rely on economic forces that yield a positive link between volatility and investment, including precautionary savings, time to build, and investment irreversibility.[4]

Most asset-pricing studies argue for a negative effect of aggregate volatility on financial variables. Bansal, Khatchatrian, and Yaron (2005) show that higher aggregate volatility depresses asset-valuation ratios. Boguth and Kuehn (2013) show that consumption volatility is a negatively priced risk. Related, Drechsler and Yaron (2011) and Shaliastovich (2015) show that higher aggregate volatility increases risk premia. Bansal et al. (2014) find that the market price of aggregate volatility risk is negative. Ai and Kiku (2016) argue that higher aggregate volatility may decrease the value of growth options.

Other studies highlight the negative impact of different volatility facets. Croce, Nguyen, and Schmid (2012) and Pastor and Veronesi (2012) demonstrate the negative effect of policy uncertainty on prices. Van Nieuwerburgh and Veldkamp (2006) show that higher belief uncertainty generates slow recoveries and countercyclical movements in asset prices. Herskovic et al. (2016) show that the common component of idiosyncratic volatility raises the household's marginal utility and is negatively priced. Dew-Becker et al. (2017) find that realized variances are negatively priced.

[4]See, e.g., Abel and Eberly, 1996; Bar-Ilan and Strange, 1996; Gilchrist and Williams, 2005; Jones et al., 2005; Malkhozov, 2014; and Kung and Schmid, 2015. For a comprehensive survey of uncertainty impact on macroeconomic quantities, refer to Bloom (2014).

Fewer financial studies argue for a positive link between volatility and valuations. Campbell et al. (2018) analyze aggregate volatility in an extended version of ICAPM and find that in a recent sample, equities have positive exposure to volatility. Pastor and Veronesi (2009) show that stock prices rise with higher uncertainty during times of technological revolutions. Different frameworks exhibit an ambivalent link between volatility and returns. Segal, Shaliastovich, and Yaron (2015) show that the positive and negative semivariances of industrial production have opposite impact on stock and bond prices.[5]

The second strand of related literature discusses the role of investment technology shocks for the business cycle and asset prices. The focus of this literature so far is on first-moment innovations, as opposed to second-moment shocks, which are at the focus of this paper. Many macroeconomic studies stress the importance of investment shocks for business cycle fluctuations.[6] The studies of Christiano and Fisher (2003), Papanikolaou (2011), and Garlappi and Song (2016), among others, highlight the ability of IST to explain the equity premium puzzle. Importantly, in this paper I do not examine IST shocks but rather focus on the total TFP of the investment sector and its volatility. This is because the empirical measures of sectoral TFPs (and volatilities) directly map to the specification of the primitive shocks in my model, while IST (and its volatility) would be a mixture of my model's primitives. I find that sectoral TFP volatility shocks can also contribute positively and significantly to the equity premium in general equilibrium. Investment specific innovations are shown to be helpful in capturing certain return spreads: value spread (see Papanikolaou, 2011), spreads based on investment, idiosyncratic volatility (see Kogan and Papanikolaou, 2013; Kogan and Papanikolaou, 2014), and commodity basis spread (see Yang, 2013). Li (2018) argues that IST shocks can explain the momentum spread, though Garlappi and Song (2016) find that the magnitude of this spread captured by these shocks is low at quarterly frequency. My study shows that investment TFP volatility shocks can capture a significant fraction of the momentum spread at quarterly frequency.[7]

3. The facts

In this section, I empirically examine the growth and pricing implications of sectoral first-moment TFP innovations and of sectoral TFP volatility shocks. Sections 3.1 and 3.2 describe the data and methodology used to construct first- and second- moment sectoral TFP shocks empirically. In Section 3.3, I analyze the effects of sectoral volatility

[5]Related, Patton and Sheppard (2015) show that negative semivariances of returns leads to higher future return volatility. Other related papers include Feunou et al., 2013; Bekaert and Engstrom, 2017; Bekaert, Engstrom, and Ermolov, 2015; Colacito, Ghysels, and Meng, 2016; McQuade, 2014; and Feunou, Jahan-Parvar, and Okou, 2015.

[6]See, e.g., Greenwood, Hercowitz, and Krusell, 1997; Greenwood et al., 2000; Fisher, 2006; Comin and Gertler, 2006; Jaimovich and Rebelo, 2009; Justiniano, Primiceri, and Tambalotti, 2010; and Basu, Fernald, and Kimball, 2006.

[7]More broadly, this paper is related to production based asset-pricing papers, which relate firms' investment-related policies to their cost of capital. For example, Liu, Whited, and Zhang (2009) find that conditional expectations of stock returns correlate positively with expectations of returns on investment. Belo, Lin, and Bazdresch (2014) provide an investment-based model to explain why firms with high hiring rates earn lower returns, while Jones and Tuzel (2013) offer a framework to explain why firms with higher inventory growth earn lower returns, relying on adjustment costs channels. Gârleanu, Kogan, and Panageas (2012) and Loualiche (2016) study displacement risk to rationalize the value premium and markups behavior. Other studies discussing asset-pricing moments in a general equilibrium production models include, among others, Jermann, 2010; Berk, Green, and Naik, 1999; Tallarini, 2000; Boldrin, Christiano, and Fisher, 2001; Gomes, Kogan, and Zhang, 2003; Carlson, Fisher, and Giammarino, 2004; Zhang, 2005; Croce, 2014; Kaltenbrunner and Lochstoer, 2010; Gomes and Schmid, 2010; Favilukis and Lin, 2013; Eisfeldt and Papanikolaou, 2013; Lustig, Roussanov, and Verdelhan, 2011; Lin, 2012; and Ai, Croce, and Li, 2013.

shocks on macro quantities such as output, consumption, investment, R&D, and markups. In Section 3.4, I examine the implications of sectoral shocks for cross-sectional risk premia. I highlight the asset-pricing role of sectoral TFP volatility shocks, above and beyond sectoral first-moment shocks, in Section 3.5.

3.1. Data

In the benchmark analysis, I use quarterly macroeconomic growth data from 1947-Q2 to 2014-Q2.[8] Consumption and output data come from the Bureau of Economic Analysis (BEA) National Income and Product Accounts (NIPA) tables. Consumption corresponds to the real per capita expenditures on nondurable goods and services and output is real and per capita gross domestic product. Capital investment data are from the NIPA tables. Data on total hours of nonfarm business sector are from the Bureau of Labor Statistics (BLS). Quarterly sales, capital expenditures, and net earnings for public firms are from Compustat. Quarterly Compustat data start at 1962-Q1 due to sparsity of data prior to this date. All nominal time series are adjusted for inflation using Consumer Price Index from BEA. Data on price deflators of nondurables and services, and on equipment goods, are also from NIPA tables. Total factor productivity data are taken from the Federal Reserve Bank of San Fransisco. Asset-price data on the three-month Treasury bill rate and on the stock price of the market portfolio are from the Center for Research in Security Prices (CRSP). I adjust the nominal short-term rate by the expected inflation to obtain a proxy for the real risk-free rate. Data on equity portfolios sorted on size, book-to-market ratio, momentum, operating profitability, and idiosyncratic return volatility are from the Fama-French Data Library.

3.2. Construction of sectoral shocks

I obtain quarterly aggregate and sectoral TFP data from Basu, Fernald, and Kimball (2006) and Fernald (2012). The aggregate TFP is computed as the difference between the log change in output and the factor-share weighted log change in capital and labor inputs. Using the relative prices of investment goods, Fernald (2012) decomposes the aggregate TFP time series into separate sectoral TFP time series, for the (nonstructures, nonresidential) "investment" sector and the "consumption" sector. Consumption in this context means everything that is not in the investment sector (i.e., everything other than equipment good producers). The sectoral TFP data of Fernald (2012) provide the total Solow residual for both sectors and account for time variation in the output share of the investment sector. Further description of the sectoral productivity data of Fernald (2012) is available in the Online Appendix Section OA.1.1.[9]

In the model described in Section 4, the primitives are Hicks-neutral productivity shocks and their respective total volatilities. As such, Fernald (2012) data directly capture the fundamentals of the model.[10] Consistent with other

[8]The start date is restricted by the availability of quarterly data postwar. The end date is based on the availability of data when the work on this study began.

[9]The data of Basu, Fernald, and Kimball (2006) and Fernald (2012) utilized in this paper are based on the release that ends at 2014-Q2. I divide the obtained quarterly consumption and investment TFP log-growth time series by four to express sectoral TFP growth at quarterly rates (Basu, Fernald, and Kimball (2006) multiply each quarter's TFP growth observation by a constant factor of 400 to express the time series at an annualized percent change).

[10]A related empirical approach that is common in the literature would be to measure IST shocks, and their volatility. However, as IST is effectively a combination of consumption and investment TFPs (the ratio between the two), its volatility would not directly map to total volatility of the investment sector but rather to a mixture of the sectoral volatilities.

studies that utilize the TFP data of Basu, Fernald, and Kimball (2006) and Fernald (2012) (see, e.g., Kogan and Papanikolaou, 2014; Garlappi and Song, 2016), I use the log-growth of consumption TFP and investment TFP as the respective sectoral first-moment TFP innovations. This is also consistent with the fact that in the model, the sectoral TFPs are random walks. I denote these first-moment innovations as ΔC-TFP and ΔI-TFP, respectively, where C is short for consumption, and I is short for investment.

To obtain second-moment (volatility) TFP shocks, I follow four steps. First, I filter the sectoral TFP growth rates using an AR(k) filter, where k is chosen by Akaike information criterion. I denote the residuals obtained from these filtrations by $\{\varepsilon_{j,t}\}, \quad j \in \{C, I\}$. Second, I construct sectoral realized variances $RV_j, \quad j \in \{C, I\}$, from the sectoral TFP residuals over a window of W quarters:

$$RV_{j,t-W+1\to t} = \Sigma_{\tau=t-W+1}^{t} \varepsilon_{j,\tau}^2. \tag{1}$$

These realized variations capture ex-post (or backward-looking) volatility in each sector. Third, to make the volatilities forward-looking, in line with the model, I project future sectoral log realized variances on a set of predictors, denoted by Γ_t:

$$\log(RV_{j,t+1\to t+W}) = b_0 + b'\Gamma_t + error. \tag{2}$$

The exponentiated fitted value of these projections are the sectoral ex-ante TFP volatilities ($V_j = exp(\hat{b}_0 + \hat{b}'\Gamma), \quad j \in \{C, I\}$). The log transformation ensures that the ex-ante volatility measures remain strictly positive.[11] Lastly, I use the log first-difference of the sectoral ex-ante TFP volatility series as the sectoral TFP volatility shocks. I denote these shocks as ΔC-TFP-VOL and ΔI-TFP-VOL. This step is a reduced-form way to obtain a proxy of second-moment shocks, which is both in line with the construction of the first-moment innovations, and does not require further filtering. However, the empirical results are still robust when the total ex-ante volatilities are used in the various projections, instead of their first differences (see further details in Online Appendix Section OA.1.6).

In the benchmark case, I set $k = 3$ and $W = 8$ quarters. With eight quarters used to construct realized variances, the sectoral volatility series start at 1949-Q1 and end at 2014-Q2. Motivated by the general equilibrium setup, the benchmark predictors used, Γ_t, are the four variables that are sufficient describe the economy's evolution (state): consumption and investment TFP growth and the two sectoral realized variances. In Online Appendix Section OA.1.6, I discuss the exclusion or inclusion of other predictors. Following these steps, I obtain four shocks: ΔC-TFP and ΔI-TFP, capturing (first-moment) sectoral TFP innovations, and ΔC-TFP-VOL and ΔI-TFP-VOL, capturing second-moment sectoral TFP shocks.

Panel A of Table **1** reports the mean, standard deviation, skewness and autocorrelation coefficients of the sectoral

[11] The projection is performed using the full sample as the quarterly postwar sample is relatively short and does not admit enough statistical power for a rolling window projection. In spite of a potential look-ahead bias in the ex-ante volatilities, there is little concern that this drives the empirical results. Both sectoral volatilities are constructed using the same projection (2) and using the same predictors Γ_t. This implies that any look-ahead bias in both volatilities is intrinsically the same and cannot account for the opposite interactions of volatilities with macro variables and prices. Moreover, when projection (2) is applied to a subsample of 1964-2014 (see Table OA.1.11 in Online Appendix), the results are still robust.

TFP volatilities. The ex-ante volatility series of the investment sector has a higher mean than that of the consumption sector. Other moments are quite symmetric. The mean, standard deviation, and autocorrelation of consumption TFP volatility are $4.3{\cdot}10^{-4}$, $1.6{\cdot}10^{-4}$, and 0.78, respectively. For investment TFP volatility, these moments are $5.1{\cdot}10^{-4}$, $1.5{\cdot}10^{-4}$, and 0.75, respectively. Panel A of Table **1** also shows the sectoral TFP volatilities' moments in National Bureau of Economic Research (NBER) recessions and expansions. During recessions, the mean of both volatilities is higher than in expansions. The volatility-of-volatility (standard deviation) is also greater in recessions.

As the TFP of the consumption and the investment sectors comove, their volatilities are also correlated. Panel B of Table **1** reports the correlation between the sectoral TFP realized variations during the full sample, expansions, and NBER recessions. For the full sample, the contemporaneous correlation is 0.84, and it is slightly lower during economic recessions. Panels (a) and (b) of Fig. **1** present the sectoral realized TFP volatilities (variations) over time. The sectoral TFP variation of each sector exhibits significant fluctuations over the sample period. Both feature occasional positive spikes, consistent with the positive skewness reported in Table **1**. In both sectors, the fluctuations are attenuated after 1985, consistent with the Great Moderation shown by Stock and Watson (2002).

Fig. **2** shows the joint evolution of the two sectoral TFP variations during the Great Moderation era, when the magnitude of the two is more easily comparable. The bar over the figure marks in red periods in which the TFP variation of the consumption sector dominates that of the investment sector. In these regimes, there is more volatility in the consumption sector compared to the investment sector. The bar shows in blue regimes in which the investment sector's TFP variation dominates that of the consumption sector. By and large, periods that are dominated by consumption (investment) TFP variation are recessionary (expansionary). The variation of consumption's TFP dominates during the early 90s recession, the dot-com recession, and during most of the Great Recession. By contrast, periods in which the TFP variation of the investment sector dominates include the inception of the Great Moderation, the information technology epoch of the mid-90s, and the housing boom of early 2000s.

To further distinct between the two sectoral volatilities, Fig. OA.1.1 in the Online Appendix shows the component of investment TFP volatility that is orthogonal to consumption TFP volatility. The orthogonal component is obtained from the residuals of the projection of investment TFP volatility on consumption TFP volatility. The orthogonal investment TFP volatility is procyclical. It decreases during the Great Recession and rises during the high-tech revolution of mid-to-late 1990s. Intuitively, one expects investment TFP volatility to rise at times when there is a new vintage of capital to be absorbed, at times of creative destruction, or when there is a new infrastructure technological advancement at an early stage (a blueprint). The invention of the Internet is a prominent example of the latter. Many investment firms (e.g., IBM and HP) were involved in the R&D process of what later became the World Wide Web.

3.3. Sectoral shocks and the macroeconomy

3.3.1. Implications for aggregate growth

In this section, I show the interaction between the sectoral volatilities and the macroeconomy. I establish the first stylized fact:

Fact I: *Consumption (investment) sector's TFP volatility predicts negatively (positively) the growth of key macroeconomic variables: consumption, output, investment, and labor.*

I project future cumulative macroeconomic growth rates, of horizon h quarters ahead, on the current proxies for sectoral first- and second- moment TFP shocks:

$$\frac{1}{h}\sum_{j=1}^{h}\Delta y_{t+j} = \beta_{0,h} + \beta_h' X_t + error, \quad (3)$$

where $X_t = [\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t]$. y is a macroeconomic log-variable of interest, and the forecast horizon h varies between 1 to 20 quarters. Table **2** shows the slope coefficients, along with the adjusted R^2 of the regressions, for aggregate cash flow growth variables–consumption, GDP, corporate sales, and earnings. Table **3** shows the evidence for input growth measures–capital inputs: nonresidential capital investment, corporate capital expenditures, and the relative price of investment goods, as well as labor inputs: total hours worked and wages. Similarly, Panel A of Table **4** presents the results for measures of R&D activity: the growth rates of R&D's contribution to GDP, the growth rate of nonresidential R&D investment, and the ratio between R&D investment to total private fixed investment.

Across the various macroeconomic growth rates and predictive horizons, the slope coefficient on consumption TFP innovation is always positive and almost always significant. With some contrast, investment TFP innovation's loadings are mostly positive in short predictive horizons but turn negative for longer-run predictive projections. Investment innovations also have strictly negative loadings in aggregate prices projections: wages and the relative price of investment and in the R&D projections. The negative loadings on investment TFP innovations, in particular for consumption, GDP, and R&D, are broadly consistent with recent empirical evidence of Basu, Fernald, and Kimball (2006) and Liu, Fernald, and Basu (2012) that investment technology shocks can be contractionary and suppress investment in the medium run.

Consumption TFP volatility carries always a negative slope coefficient. It is statistically significant mostly in shorter horizons of one up to eight quarters ahead. This is the typical negative interaction of volatility and growth, consistent with Bloom (2009) and others. By contrast, investment TFP volatility has always a positive correlation with future growth. This positive interaction is mostly significant at horizons of one quarter to three years ahead. For R&D growth, this positive interaction is even more pronounced, up to five years ahead.

The adjusted R^2 is quite substantial in predicting short-horizon GDP, capital investment, and hours growth (between 15%-22%). The adjusted R^2s in all predictive regressions are substantively higher when the sectoral volatilities are included as predictors, compared to the case in which they are excluded. When sectoral volatilities are included, the adjusted R^2 in predicting one-quarter-ahead consumption, output, and capital investment growth is 6.7%, 14.8%, and 22.3%, respectively. In untabulated results, I find that when the volatilities are excluded (using only first-moment innovations as predictors), the adjusted R^2 is only 3.3%, 7.5%, and 1%, respectively.

The positive interaction between investment TFP volatility and economic growth is manifested also at the industry level. Panel B of Table **4** presents the evidence of projecting annual R&D investment growth rates of R&D-intensive industries on the sectoral shocks. The sectoral volatilities predict future industry R&D investment growth with opposite signs. As R&D activity in these industries is a major endogenous driver of aggregate technological progress, these projections suggest that investment TFP volatility should positively affect future productivity. This prediction is tested and confirmed in Section 3.6.

In Table **5**, I repeat the projections of former tables, replacing the y variable to the business cycle component (obtained via one-sided HP filter) of key macro variables, averaged over the predictive horizons. Averaging the business cycle extracts the "long-run" component of variables. The variables considered include consumption, GDP, investment, and hours. The table conveys a similar message to the growth-rate projections. Consumption (investment) TFP volatility shocks predict negatively (positively) variables' business cycle component.

Though the projections in Tables **2** - **5** are multivariate and account for the factors' correlations, I orthogonalize the effect of TFP volatility shocks via impulse responses in Fig. **3**. The impulse responses are computed from a first-order vector autoregression—VAR(1)—that includes consumption and investment TFP innovations, consumption and investment TFP volatilities, and the macroeconomic variable of interest (in that order). I plot one standard deviation Cholesky TFP volatility shock impulse responses to detrended consumption, capital investment, and private sector's output. Fig. **3** illustrates the expansionary (contractionary) pattern for investment (consumption) TFP volatility. The impulse responses (IRF)s are persistent up to 20 quarter ahead for investment and output while relatively short lived for consumption.

The opposite growth implications of the sectoral TFP volatilities can also be manifested using an event-study methodology (see Online Appendix Section OA.1.3). In Section OA.1.2 of the Online Appendix, I discuss the relation between the sectoral volatilities and IST shocks. I find that consumption (investment) TFP volatility increases (decreases) future IST growth. This is consistent with the evidence in Table **3** that consumption (investment) TFP volatility decreases (increases) the relative price of capital goods, which relates negatively to IST.

3.3.2. Implications for markups

Section 3.3.1 shows that consumption TFP volatility drops wages and the relative price of investment goods. Investment TFP volatility induces the opposite effect. Thus, consumption (investment) TFP volatility drops (increases) the marginal cost of production. As markups are inversely related to this marginal cost, an immediate corollary is that consumption (investment) TFP volatility should increase (drop) markups, on average.

To test this prediction, I construct measures of aggregate markups using the methodology of Rotemberg and Woodford (1999). The basic markup proxy is related to the inverse of the business sector labor share. Following Rotemberg and Woodford (1999), I adjust this measure for non-Cobb-Douglas production and labor adjustment costs. The construction details are provided in Table **6**. I project future cumulative markups, of horizon h quarters ahead, on the current proxies for sectoral first- and second- moment TFP shocks:

$$\frac{1}{h}\sum_{j=1}^{h}\text{markup}_{t+j} = \beta_{0,h} + \beta_h' X_t + error, \tag{4}$$

where $X_t = [\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t]$. The forecast horizon h varies between 1 to 20 quarters. The results are reported in Panel A of Table **6**. Consistent with the prediction, consumption and investment TFP volatilities have opposite interactions with future markups. The sectoral first-moment TFP innovations also relate to future markups with opposite signs. Consumption (investment) TFP innovation drops (increases) aggregate markups, in line with how these innovations impact wages and prices.

Without labor frictions, wages are the same for both consumption and investment good producing firms. Consequently, as consumption (investment) TFP volatility decreases (increases) wages, it should increase (decrease) markups for both sectors. To test this prediction, I construct a proxy for the consumption sector's markups, using annual data on labor share, hours, and output for nondurable good producers. I construct a proxy for the investment sector's markups using similar data for durable good producers (consistent with Basu, Fernald, and Kimball (2006) that attribute durable good production to the investment sector since in a two-sector model, the investment sector is producing all depreciable equipment). Panel B of Table **6** shows the results of repeating projection (4) using annual sectoral markup data. Consistent with the prediction, consumption (investment) TFP volatility increases (drops) markups for both nondurable and durable good producers.

3.4. Sectoral shocks and the cross-section of returns

In this section, I show the implications of sectoral first and second moment TFP shocks for the cross-section of stock returns. Since the sectoral volatilities interact with aggregate cash flow growth rates in an opposite way, I hypothesize that the volatilities would have opposite pricing implications. Consistently, cross-sectional return-based analysis yields the second stylized fact:

Fact II: *Consumption (investment) TFP volatility has a negative (positive) market price of risk. Hence, investors' marginal utility rises (drops) with consumption (investment) uncertainty.*

A portfolio risk premium is given by the product of the market prices of risks $\Lambda = (\lambda_{\text{C-TFP}}, \lambda_{\text{I-TFP}}, \lambda_{\text{C-TFP-VOL}}, \lambda_{\text{I-TFP-VOL}})$, the variance-covariance matrix of the risk factors, denoted by Ω, which captures the quantity of risk, and the exposure of the portfolio to the underlying macroeconomic risk β_i:

$$E[R_{i,t+1} - R_{f,t}] = \Lambda'\Omega\beta_i. \tag{5}$$

I estimate the equity exposures β_i and the market prices of risks Λ using a standard Fama and MacBeth (1973) procedure. I obtain the return betas by running a multivariate regression of each portfolio's log excess return on the sectoral shocks:

$$\begin{aligned} r^e_{i,t} &= \text{const} + \beta_{i,C-TFP}\Delta\text{C-TFP}_t + \beta_{i,I-TFP}\Delta\text{I-TFP}_t \\ &\quad + \beta_{i,C-TFP-VOL}\Delta\text{C-TFP-VOL}_t + \beta_{i,I-TFP-VOL}\Delta\text{I-TFP-VOL}_t + \text{ error.} \end{aligned} \tag{6}$$

The slope coefficients in the above projection represent the portfolio's exposures to sectoral TFP innovation risks and sectoral TFP volatility risks. Next, I obtain factor risk premia $\tilde{\Lambda}$ from a cross-sectional regression of average excess returns on the estimated betas:

$$\overline{R^e_i} = \tilde{\lambda}_{\text{C-TFP}}\beta_{i,\text{C-TFP}} + \tilde{\lambda}_{\text{I-TFP}}\beta_{i,\text{I-TFP}} + \tilde{\lambda}_{\text{C-TFP-VOL}}\beta_{i,\text{C-TFP-VOL}} + \tilde{\lambda}_{\text{I-TFP-VOL}}\beta_{i,\text{I-TFP-VOL}} + \text{error.} \tag{7}$$

I impose a zero-beta restriction in the estimation and thus run the regression without an intercept. The implied factor risk premia, $\tilde{\Lambda} = (\tilde{\lambda}_{\text{C-TFP}}, \tilde{\lambda}_{\text{I-TFP}}, \tilde{\lambda}_{\text{C-TFP-VOL}}, \tilde{\lambda}_{\text{I-TFP-VOL}})$, are a function of both the vector of the underlying prices of risks Λ and the quantity of risks $\Omega : \tilde{\Lambda} = \Omega\Lambda$. To compute the underlying prices of risk Λ I premultiply the factor risk premia $\tilde{\Lambda}$ by the inverse of the quantity of risk matrix Ω. To obtain standard errors, I embed the two-stage procedure into generalized method of moments (GMM), which allows to capture statistical uncertainty in estimating jointly asset exposures and market prices of risk. In the benchmark implementation, the cross-sectional assets includes the market return, the cross-section of ten portfolios sorted on size, book to market, and momentum. Panel A of Table **7** shows the market prices of risks estimates along with their *t*-statistics.

Consumption sector's TFP first-moment innovations have a positive and significant market price of risk. The market price of risk of investment TFP first-moment innovations is also positive yet not statistically significant.[12] Panel A shows that the market price of investment (consumption) TFP volatility is positive (negative). Both are statistically significant. This is consistent with the effect of sectoral volatilities on the evolution of consumption. The next stylized fact is evident from Panel B of Table **7**:

Fact III: *For most equities, the risk exposures to consumption (investment) TFP volatility are negative (positive).*

All assets have a positive exposure to consumption TFP first-moment innovations and a negative exposure to investment TFP first-moment innovations. All equities, except for portfolios comprised of very small stocks, are exposed in a similar fashion to sectoral TFP volatility shocks. By and large, consumption TFP volatility lowers equity valuations (negative betas), while investment TFP volatility raises equity valuations (positive betas).

[12] Importantly, this is not at odds with previous studies who find that IST shocks have a significant market price of risk (see, e.g., Kogan and Papanikolaou (2013) who find a negative market price for IST shocks and Garlappi and Song (2016) who find these shocks to be positively priced). This is because investment TFP and IST are defined and measured differently. Investment TFP refers to the total Solow residual of the investment sector, while an IST shock is the log-difference between investment and consumption TFPs.

3.5. The pricing role of sectoral volatilities

Section 3.4 demonstrates that the sectoral TFP volatility shocks are priced in the cross-section of returns. A production-based stochastic discount factor that excludes the volatility shocks is statistically misspecified. In this section, I show that this misspecification can also be economically important for matching asset-pricing moments. The sectoral volatility shocks, particularly in the investment sector, improve the fit of the production factor model to the data along several cross-sections and mainly along the momentum spread.

To highlight the importance of TFP volatility shocks, I compare two factor model specifications. In the first specification, I include four risk factors: consumption and investment (first-moment) TFP innovations and consumption and investment TFP volatility shocks. The second model excludes the sectoral volatilities and only includes two sectoral first-moment TFP innovations. I tabulate a summary of the asset-pricing implications for both models: in Table **8** for the four-factor model and in Table **9** for the two-factor model.

Panel A of Tables **8** and **9** reports the adjusted R^2 in a second-stage projection of a Fama-Macbeth procedure (i.e., mean excess returns on a constant and the cross-section of risk exposures), performed separately for each of the models. The cross-sectional assets in each case are identical to those used in Section 3.4. The fit of the four-factor model is significantly better than the two-factor specification. The adjusted R^2 rises from about 50% with only sectoral first-moment innovations to 70% when volatilities are included. Panel B of Tables **8** and **9** reports the factor model-implied quantile based quarterly return spreads, for several cross-sections, against their data counterpart. The dimensions tabulated include size, book to market, momentum, lagged firm value to capital value (Tobin's Q), operating profitability, and idiosyncratic return volatility spreads.

The fit of the four-factor model is significantly improved along the momentum, Q, operating profitability, and idiosyncratic volatility dimensions in comparison to the two-factor specification. In the data, the quarterly momentum spread amounts to 2.65%. When volatilities are included, the factor model-implied spread amounts to 0.83%. While this is only 30% of the data spread's magnitude, in the model without volatilities, the model-implied spread bears the wrong sign and amounts to -0.50%. Similarly, the model-implied spreads based on operating profitability and idiosyncratic volatility exhibit an opposite sign compared to the empirical counterparts when the sectoral volatilities are excluded but become close to the data once the volatilities are included. The model-implied quarterly Q-spread is 1.28% when volatilities are included but only 0.41% without them. In the data, this quarterly spread is 0.98%.

Li (2018) argues that IST innovations can explain the momentum spreads at annual frequency. Yet, the ability of IST innovations to explain the momentum spread is disputed in the literature. Garlappi and Song (2016) find that the fraction of the momentum spread, captured by these innovations, is low at quarterly frequency. Although I do not explicitly consider IST shocks, but rather the total investment TFP innovations, Table **9** is broadly consistent with the notion that investment first-moment innovations alone are not enough to explain the quarterly momentum spread. By contrast, I find that the ability of investment TFP volatility shocks to explain the momentum spread is large and economically significant. Panel B of Table **8** shows the decomposition of the model-implied momentum spread to the contribution of each risk factor. The momentum spread, emanating from investment TFP volatility risk channel, is 2.43% compared to 2.65% in the data (90% of the momentum spread's magnitude). Tables **8** and **9** yield the following stylized fact:

Fact IV: *Investment TFP volatility shocks are helpful in capturing the magnitude of the momentum and investment-based spreads.*

3.6. Volatility feedback to technological growth

I examine whether the sectoral TFP volatilities affect the evolution of future productivity. I project one-quarter-ahead consumption- and investment-TFP growth rates on the current level of the four factors: two sectoral first-moment TFP innovations and two sectoral TFP volatilities. The results are reported in Table **10**. Investment and consumption TFP growth rates depend significantly (and positively) on their own lagged value. In addition, there is a positive and significant interaction between investment TFP volatility today to one-quarter-ahead consumption TFP growth. I denote this feature the volatility feedback.

This feedback could be interpreted through the lens of endogenous growth models. One way to rationalize this volatility feedback is through the effect of uncertainty on growth options in the investment sector. In endogenous growth models in the spirit of Romer (1990) and Kung and Schmid (2015), an increase in the number of patents endogenously increases the productivity of consumption good producers. Assume a two-sector endogenous growth model in which patent holders (intermediary investment good producers) also own a stock of real growth options. More volatility in the investment sector increases the value of these growth options, thus increasing the market value of patent holders. By free entry into the R&D sector, this rise in firm value encourages more innovators to enter, create new patents, and results in increased productivity for the final consumption good producers one period ahead.

Although the volatility feedback can be endogenized, for parsimony I refrain from explicitly modeling the endogenous growth mechanisms and incorporate the volatility feedback in a reduced-form manner into the model in Section 4. This empirical feedback is not essential to qualitatively rationalize the impact of sectoral volatilities on macro quantities or on stock prices. However, it is useful to quantitatively enhance certain economic channels.[13]

3.7. Robustness

In Section OA.1.6 of the Online Appendix, I consider various robustness checks for the empirical results. In the first set of checks, I alter the construction of sectoral volatilities by changing key implementation choices used in Eq. (1) and (2). I consider different predictors for predicting future realized variances, changing the window for the realized variance computation, or using the total ex-ante variances as opposed to their first differences. In the second set of checks, I employ different proxies for the sectoral volatilities. I consider using the dispersion of

[13]A negative interaction from consumption TFP volatility to one-quarter-ahead consumption TFP is also statistically significant in Table **10**. This negative interaction is not qualitatively or quantitatively important to explain any of the stylized facts. For parsimony, this negative interaction is not incorporated into the model in Section 4 (including it would only strengthen the model results).

sales of consumption versus investment firms as sectoral volatilities or replacing investment TFP volatility by IST-volatility. Lastly, I consider miscellaneous other checks, such as restricting the sample to start at 1964 (modern sample) or using capacity-utilization adjusted TFPs and their volatilities. Across all checks, the opposite growth and pricing implications of the sectoral TFP volatilities still hold. Importantly, the correlation between consumption and investment TFP volatilities typically drops across these different checks, while the results are materially unchanged, suggesting that the degree of correlation between the sectoral volatilities does not drive the empirical results.[14]

4. The model

4.1. Model description

This section outlines the general equilibrium model used to rationalize the empirical findings. The economy features several channels that are highlighted in the macro literature (see, e.g., Smets and Wouters, 2007; Papanikolaou, 2011; Liu, Fernald, and Basu, 2012; Garlappi and Song, 2017). Below I provide a short description of the economy along with key notations. The full details of the model's parameter, variables, and equations are given in Appendix A. Fig. OA.1.3 in the Online Appendix provides a schematic illustration of the model.

The production economy is comprised of two good-producing sectors: a "consumption" sector and an "investment" sector. Consumption (investment) sector's variables are denoted with subscript c (i). In each sector $j \in \{c, i\}$, a mass of intermediate good producers produce differentiated consumption or investment goods. They produce their output using Cobb-Douglas technology over capital ($k_{j,t}$) and labor ($n_{j,t}$), where α_j is the capital share of output, and capital depreciates at rate δ. The output of all intermediate good producers in sector $j \in \{c, i\}$ is subject to a sectoral productivity shock ($z_{j,t}$), whose innovations feature stochastic sectoral TFP volatility ($\sigma_{z,j,t}$). Motivated by the empirical facts, investment TFP volatility, $\sigma_{z,i,t}$, feeds positively to future growth of consumption TFP, $z_{c,t+1}$ (the strength of this volatility feedback is governed by the parameter τ). The intermediate good producers in each sector face monopolistic competition (the degree of substitutability between the intermediate inputs is governed by the parameter μ_j). These producers choose their nominal product price but face adjustment costs in doing so (governed by an adjustment cost parameter ϕ_P). An aggregator in each sector converts the sectoral intermediate goods to a final good. The consumption sector's aggregator sells the final consumption good, C_t, to the household. The investment sector's aggregator sells the final investment goods, $Y_{i,t}$, to intermediate good producers in both sectors who wish to invest, under the equilibrium relative price of investment goods, $P_{i,t}$.

The economy is populated by a representative household that owns all firms in the economy and supplies them with labor. It derives utility from an Epstein and Zin (1989) and Weil (1989) utility over a stream of consumption goods C_t and disutility from labor. The household preferences are governed by three main parameters: β, the time

[14] For instance, the degree of correlation between the ex-ante sectoral volatilities varies significantly (from below 0.3 to over 0.9) based on the implementation choices (e.g., which variables are used for Γ_t). Nonetheless, the empirical results regarding the opposite impact of the sectoral volatilities are robust to alternative choices of Γ_t (see, e.g., Table OA.1.7 in the Online Appendix). Section OA.1.4 in the Online Appendix provides further discussion on how the cross-volatility correlation does not play an important role in driving the empirical results.

discount rate, γ, the relative risk aversion, and ψ, the intertemporal elasticity of substitution (IES). When $\gamma > \frac{1}{\psi}$, the household has preferences exhibiting early resolution of uncertainty. A monetary policy authority sets the nominal interest rate according to a Taylor (1993) rule. This Taylor rule, along with the household's pricing kernel, pins down inflation.

The calibration of the full model is specified in Appendix B. I solve the model via third-order perturbations method. A characterization of the equilibrium conditions is specified in Appendix C.

4.2. Model intuition

A fundamental difference exists between consumption and investment shocks in the model. Investment shocks have endogenously a prolonged effect on the economy, as they affect the creation of the stock of capital, which is slowly depreciating. Consumption shocks have a short-run effect on the economy, as they only rescale the flow of consumption. This distinction between an effect on a stock versus a flow implies that when the volatility rises in one of the sectors, the economy responds differentially. Generally, when volatility rises, two opposite forces are at work: a (negative) income effect, to do more precautionary savings, and a (positive) substitution effect on consumption that inhibits saving. The agent has a more positive interest to invest (i.e., the income effect dominates) when investment TFP volatility rises, as the stock risk affects the entire path of future growth. The agent has a negative interest to invest when consumption TFP volatility rises, as the flow risk resembles a pure one-shot capital risk that the agent is adverse to (it depresses investment so long as the substitution effect dominates). As common in production economies, investment and stock prices comove. Since investment responds differentially to the two volatility shocks, so do stock prices. Though volatilities' impact on investment and stock prices can be reconciled in a perfect competition setup, such simplified model generates divergence of investment and consumption in response to volatility shocks. Markups, generated via monopolistic competition and sticky prices, create a wedge that induces comovement of consumption and investment to volatility shocks.

The rest of this section develops this intuition by shutting down certain model ingredients that allow to highlight the core economic forces. Assume a two-sector economy under perfect competition, inelastic labor supply, and no adjustment costs.[15] Under these assumptions, I can collapse the model detailed in Appendix A to a representative

[15]Specifically, I assume that (1) there is no disutility from labor $\xi = 0$, so labor supply is inelastic; (2) $\mu_j \to \infty, \quad j \in \{c, i\}$, implying perfect competition in both sectors; (3) $\tau = 0$, that is, no volatility feedback to future TFP growth; (4) $\phi = 1$, so there are no capital adjustment costs; and (5) the capital share of output is the same in both sectors $\alpha_c = \alpha_i = \alpha$.

agent problem, as follows:

$$V_t(\Gamma_t) = \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \left\{ (1-\beta) C_t^{1-1/\psi} + \beta \left(E_t V_{t+1}(\Gamma_{t+1})^{1-\gamma} \right)^{\frac{1-1/\psi}{1-\gamma}} \right\}^{\frac{1}{1-1/\psi}} \tag{8}$$

$$\text{such that (s.t.) } C_t = z_{ct} k_{ct}^{\alpha} n_{ct}^{1-\alpha} \tag{9}$$

$$Y_{i,t} = z_{it} k_{it}^{\alpha} n_{it}^{1-\alpha} \tag{10}$$

$$k_{c,t+1} = (1-\delta) k_{ct} + I_{ct} \tag{11}$$

$$k_{i,t+1} = (1-\delta) k_{it} + I_{it} \tag{12}$$

$$I_{ct} + I_{it} = Y_{i,t} \tag{13}$$

$$n_{ct} + n_{it} = 1, \tag{14}$$

where $\Gamma_t = [k_{ct}, k_{it}, z_{ct}, z_{it}]$, $I_{j,t}$ are sectoral investments, and $\frac{z_{j,t+1}}{z_{j,t}} = \mu_{zj} + \sigma_{zj,t}\varepsilon_{j,t+1}$, for $j \in \{c, i\}$.[16] In Appendix D, I show that the solution to program (8) equals the solution of program (15), given by:

$$\tilde{V}_t(k_{ct}, k_{it}, z_{it}) = \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \left\{ (1-\beta)\left(k_{ct}^{\alpha} n_{ct}^{1-\alpha}\right)^{1-1/\psi} + \underbrace{\beta \left(E_t \left(\frac{z_{ct+1}}{z_{ct}}\right)^{1-\gamma} \right)^{\frac{1-1/\psi}{1-\gamma}}}_{\tilde{\beta}_t} \left(E_t \tilde{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1})^{1-\gamma} \right)^{\frac{1-1/\psi}{1-\gamma}} \right\}^{\frac{1}{1-1/\psi}} \tag{15}$$

$$\text{s.t. } (10), (11), (12), (13), \text{ and } (14),$$

$$\frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1}, \qquad \frac{z_{it+1}}{z_{it}} = \mu_{zi} + \sigma_{zi,t}\varepsilon_{zi,t+1}.$$

The equivalence of programs (8) and (15) relies on homogeneity of degree one of the value function in consumption TFP growth. This stems from the fact that z_{ct} is random walk, and that an Epstein-Zin utility is a homogeneous of degree one function. In economic terms, the homogeneity in consumption shocks relates to the fact that these shocks affect a flow. Such homogeneity is not admissible for investment shocks as they affect a stock.

4.2.1. Sectoral volatilities and investment implications

To understand the impact of consumption TFP volatility on investment, it is constructive to realize that higher consumption TFP volatility, $\sigma_{zc,t}$, increases the planner's effective impatience under early resolution of uncertainty. To see this, notice that in program (15), the expectation of consumption TFP growth (that is, the expression $\tilde{\beta}_t = \beta\left(E_t\left(\frac{z_{ct+1}}{z_{ct}}\right)^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}$) acts like a time "preference shock" that changes the effective time discount rate. When $\gamma > 1$,

[16]For $j \in \{c, i\}$, the parameters μ_{zj} are the sectoral TFP drifts, and $\varepsilon_{j,t+1}$ are standard normal first-moment TFP sectoral shocks. In program (8), the sectoral volatilities, $\sigma_{zc,t}$ and $\sigma_{zi,t}$, are also carried as state variables. Their law of motion is given by Eq. (A.15) and (A.16), specified in Appendix A. For short of notation, I omitted them from the vector of state variables.

$(\cdot)^{(1-\gamma)}$ is a convex function. With more consumption TFP volatility, $E_t\left(\frac{z_{ct+1}}{z_{ct}}\right)^{1-\gamma}$ increases by Jensen's inequality. When the agent has early resolution of uncertainty preferences, $\gamma > 1, \psi > 1$, and the expression $\frac{1-1/\psi}{1-\gamma}$ is negative. Thus, higher σ_{zc} lowers the effective discount factor $\tilde{\beta}$. The agent puts lower weight on the continuation value, implying a more impatient agent. Moreover, consumption TFP volatility only affects impatience, as the growth of z_c appears nowhere else in the program, except for its ex-ante impact on $\tilde{\beta}_t$.

As a result of greater impatience, when σ_{zc} rises, the agent shifts her consumption profile to the present. The agent shifts labor to the consumption sector to increase consumption today; she also increases investment in the consumption sector to ensure higher consumption in near future. Consequently, investment sector's labor drops ($n_{i,t} \downarrow$). As capital in the investment sector is predetermined, but the sectoral labor drops, higher consumption TFP volatility lowers aggregate investment, in line with the empirical findings.

Notice that the impact of σ_{zc} on patience depends on the preferences. When $\gamma = 0, 1$, there is no Jensen effect, and so consumption TFP volatility does not impact $\tilde{\beta}_t$. If $\psi < 1$, $\sigma_{z,c}$ boosts investment, as the agent becomes more patient (higher $\tilde{\beta}_t$).

The program (15) shows that consumption TFP ex-ante expectations change the effective discount rate. Beyond that, consumption TFP shocks have no other effect ex-post except for "rescaling" the flow of consumption—see Eq. (9). This is a transitory (short-run) impact. By contrast, investment innovations z_i affect multi-period stock of aggregate capital dynamics, which flows additively to both sectors. Investment innovations, consequently, have endogenously a more long-run effect. As a result, when these shocks become more volatile they induce a strong precautionary saving motive.[17]

When investment TFP volatility rises (higher σ_{zi}), the future probability of having suboptimal amount of investment goods rises. This inhibits the ability to smooth consumption, as aggregate investment goods flow to both sectors, much like total output in a one-sector economy. The household has a strong incentive to invest more in the investment sector, and consume less, by shifting labor to the investment sector ($n_{i,t} \uparrow$). Doing so ensures higher aggregate capital in the future, which acts as a buffer of savings. If a bad investment TFP shock is realized, the buffer of capital can be used to smooth consumption. Higher investment partially hedges the investment TFP volatility shock. Consequently, higher investment TFP volatility increases aggregate investment, in line with the empirical findings.

[17] Suggesting that consumption TFP has a short-run impact by rescaling consumption traces to Kimball (1994). A necessary condition for investment TFP volatility to induce precautionary saving is decreasing absolute risk aversion (see, e.g., Leland, 1968; Kimball and Weil, 2009), satisfied by Epstein and Zin (1989) utility. Quantitatively, I find that the substitution effect dominates for consumption TFP volatility iff $\psi > 1$, while for investment TFP volatility the income effect prevails for both high and low intertemporal elasticity of substitution (IES) values. The implication of investment TFP volatility on investment is consistent with the study of Jones et al. (2005), who show that in a one-sector economy, under most realistic calibrations higher volatility raises savings and growth in equilibrium. By contrast, the dependence of how investment reacts to consumption TFP volatility on the value of IES is consistent with the works of Levhari and Srinivasan (1969), Sandmo (1970), and Obstfeld (1994). In a one-sector context, these studies analyze the impact of higher volatility of multiplicative shocks, which only affect the riskiness of the return on capital (similar to consumption TFP). These models share the prediction that for high values of IES, the substitution effect dominates, and higher volatility induces less investment.

4.2.2. Sectoral volatilities and pricing implications

The logic of Section 4.2.1 implies that investment (consumption) TFP volatility, σ_{zi} (σ_{zc}), increases (lowers) the demand for investment goods (when ψ is greater than one). As a result, the relative price of new investment goods (in the decentralized economy) increases (drops) when σ_{zi} (σ_{zc}) rises. To see this, let $q_{c,t}$ be the Lagrange multiplier of constraint (11), let $q_{i,t}$ be the Lagrange multiplier of constraint (12), and let $P_{i,t}$ be the multiplier of constraint (10). By equating the marginal productivity of labor in both sectors, one obtains

$$P_{i,t} = q_{i,t} = q_{c,t}, \tag{16}$$

$$P_{i,t} = \frac{z_{c,t}}{z_{i,t}} \left(\frac{k_{c,t}}{k_{i,t}} \frac{n_{i,t}}{n_{c,t}} \right)^{\alpha}. \tag{17}$$

Since higher consumption TFP volatility σ_{zc} lowers $n_{i,t}$ and raises $n_{c,t}$, the price of new investment goods $P_{i,t}$ falls by Eq. (17). Higher investment TFP volatility σ_{zi} increases $n_{i,t}$ and lowers $n_{c,t}$, causing $P_{i,t}$ to rise. The marginal value of assets in place (i.e., Tobin's Q: q_c or q_i) should equal the marginal cost of new capital (P_i) times the marginal adjustment cost (installation cost). Without adjustment costs, we obtain Eq. (16), implying that the price of installed capital is equal in both sectors. Thus, consumption TFP volatility lowers $q_{c,t}$ and $q_{i,t}$, and the opposite happens in response to investment TFP volatility.

Firms in the model exhibit constant returns to scale. By a standard argument, Tobin's Q is a sufficient statistic for the (ex-dividend) firm values. Higher σ_{zi} increases $P_{i,t}$ and so increases both $q_{i,t}$ and $q_{c,t}$. This implies that higher investment TFP volatility increases firms' values in both sectors, and by definition, $\beta_{\text{j,I-TFP-VOL}} > 0, \quad j \in \{c, i\}$. The exact opposite logic applies to consumption TFP volatility, and implies $\beta_{\text{j,C-TFP-VOL}} < 0, \quad j \in \{c, i\}$. The risk-exposure patterns with respect to sectoral volatility shocks are consistent with the data.

4.2.3. Sectoral volatilities and the role of sticky prices

Sections 4.2.1 and 4.2.2 demonstrates that in a perfect-competition model, investment expenditures rise (drop) in response to investment (consumption) TFP volatility, in line with the data. Yet, in the simplified setup, consumption and aggregate investment diverge in response to volatility shocks. As a result, consumption TFP volatility counterfactually boosts consumption, not only contemporaneously but also in the future.[18] Counterfactual consumption behavior induces a counterfactual impact on either the sign or the magnitude of the market price of consumption TFP volatility risk.

The full model in Appendix A features time-varying markups, which rely on monopolistic competition in the two sectors, along with sticky prices in the consumption sector. As suggested in Fernández-Villaverde et al. (2015) and Basu and Bundick (2017), these model features make consumption and aggregate investment expenditures to comove

[18]In the data, consumption TFP volatility drops both consumption and investment. The comovement problem is not pertaining to investment TFP volatility. In the data, the positive effect of investment TFP volatility on detrended consumption is only significant predictively, one year ahead. By contrast, consumption TFP volatility drops consumption significantly already one quarter ahead. See Table **5**.

with respect to sectoral volatility shocks. When sticky prices are present, consumption and investment expenditures both decrease in response to consumption TFP volatility. The intuition is described below.

Section 4.2.1 shows that higher consumption TFP volatility makes the agent more impatient. This increases the demand for consumption goods and causes the agent to desire to supply more labor to the consumption sector. Consequently, wages and the price of investment drop (the price drops due to decreased demand for capital). The marginal cost of producing consumption goods declines. With Rotemberg pricing, gross markup equals the inverse of the real marginal costs. This implies that with monopolistic competition, along with sticky prices, higher consumption TFP volatility causes the markups of consumption producing firms to rise as their marginal production costs drop.

Higher markups of consumption firms lower their demand for labor at any level of wages. This is because higher markups are equivalent to a higher degree of monopolistic power, which has a rationing impact on the quantity produced, and involves less utilization of labor.[19] If the decline in labor demand from consumption producing firms is sufficiently strong, higher consumption TFP volatility would cause these firms to hire less. Hence, consumption drops upon a positive consumption TFP volatility shock, which is consistent with the data.

As labor flows out of the consumption sector, and into the investment sector, production of investment goods ($Y_{i,t}$) rises. The increased supply of investment goods, along with the reduced demand for these products from the household (due to greater impatience), causes their price P_i to further decline. If the decline in P_i is strong enough, investment expenditures, defined as $I_t = P_{i,t}Y_{i,t}$, would drop in response to consumption TFP volatility shock. This happens simultaneously with a decline in consumption, as seen in the data.

5. Quantitative model results

5.1. Macroeconomic moment implications

I simulate the model at a quarterly frequency and time aggregate the model-implied data to form annual observations. The annual moments of real (log) growth rate of consumption, investment expenditure, output, and the relative price of investment are reported in Panel A of Table **11**. Most data moments fall inside the model-implied 90% confidence intervals.

Consumption growth mean is about 2% in the model and in the data. In the model, the standard deviation of consumption growth is 2.17%, slightly higher than the data counterpart of 1.52% for the sample of 1947-2014. Yet, it is consistent with the long-run sample (1930-2014) consumption growth volatility. The autocorrelation of consumption growth is 0.54 in the model, versus 0.49 in the data. Output growth's volatility is about 2.2% in the model and the

[19]The demand curve for labor from consumption producing firms is given by

$$W_t = (1-\alpha)\frac{1}{\theta_{c,t}}k_{ct}^{\alpha}n_{ct}^{-\alpha},$$

where W_t is aggregate wage, and $\theta_{c,t}$ is the markup in the consumption sector. Thus, a higher markup $\theta_{c,t}$ shifts the labor demand curve of consumption producing firms downwards. As a result, consumption TFP volatility shock makes consumption producing firms to demand less labor.

data. The standard deviation and autocorrelation of investment growth are 6.6% and 0.30 in the model, closely related to a standard deviation of 6.75% and autocorrelation of 0.18 in the data. The mean growth rate of the relative price of investment is -0.97% empirically, while it is -0.95% in the model. The model-implied volatility of the relative investment price growth is 3.48%, closely matching its empirical counterpart of 3.62%.

5.2. Sectoral shocks and macroeconomic implications

In this section, I analyze the impact of sectoral shocks on macroeconomic quantities in the model. I plot impulse responses from sectoral volatilities to key macroeconomic variables,[20] computed for two model calibrations: (1) the benchmark case (all calibration parameters are specified in Appendix B); (2) a simplified model, with an identical calibration to the benchmark, but in which there is perfect competition and no feedback from investment TFP volatility to future consumption TFP (i.e., $\tau = 0$). Case (2) is almost identical quantitatively to the case in which there is monopolistic competition but no sticky prices (constant markups).

Fig. **4** shows model-implied impulse responses from consumption TFP volatility and investment TFP volatility shocks to aggregate consumption, Panels (a) and (d); aggregate investment expenditures, Panels (b) and (e); and aggregate output, Panels (c) and (f). All variables are real and detrended using the model's stochastic trend. Each impulse response is in units of percent change from the stochastic steady state. From panels (b) and (e), one can see a negative impact of consumption TFP volatility on investment, both at the time of the shock and up to 40 quarters ahead, and a positive impact of investment TFP volatility on investment, which persists 40 quarters ahead as well, for the two model calibrations. This pattern aligns with the empirical findings. As discussed in Section 4.2.1, the opposite effects on investment stem from precautionary saving motive induced by investment TFP volatility, and from higher effective impatience induced by consumption TFP volatility.

Panel (a) of Fig. **4** shows that in the benchmark case, consumption TFP volatility lowers consumption, in line with the data. The negative impact is a result of higher markups, which rise when consumption TFP volatility rises. As discussed in Section 4.2.3, higher markups cause consumption good producers to hire less, resulting in lower consumption production. By contrast, and consistent with the data, Panel (d) shows that investment TFP volatility generates mostly a positive impact on consumption (a large overshoot), a few periods after the shock. This is a consequence of prolonged capital buildup, triggered by this volatility shock, which translates into higher future consumption. Panel (a) shows that under perfect competition, consumption TFP volatility shock increases consumption up to 20 quarters ahead. This is counterfactual to the empirical evidence. As explained in Section 4.2.3, adding sticky prices flips the sign of consumption's response to consumption TFP volatility, making it negative, consistent with the data. Panels (c) and (f) show that output's response is strictly negative (positive) to consumption (investment) TFP volatility, for both model calibrations. This pattern is consistent with the empirical impulse responses. Adding sticky

[20]The impulse responses are computed by Monte-Carlo simulations. In each simulation $i \in \{1, 2, .., S\}$, I simulate the economy for 140 periods. Denote the simulated path of simulation i from period 100 onward by $\{p_i\}$. I then simulate the economy again, using the same shocks as were drawn before, but in period 100, I increase shock j by one standard deviation. Let the second simulated path from period 100 onward be $\{p'_i\}$. The impulse responses of shock j are given by the matrix $\frac{1}{S}\Sigma_{s=1}^{S}(p'_i - p_i)$. I pick $S = 10,000$ simulations for the impulse response computations.

prices amplifies in absolute value the magnitude of output's impulse responses. This is a result of the fact that sticky prices cause consumption and investment expenditures, which comprise total output to comove.

Fig. **5** plots impulse responses from sectoral TFP volatility shocks to hours, real wages, and the price of investment goods. In the benchmark case, investment (consumption) TFP volatility boosts (depresses) these variables. These impacts are empirically consistent. Panels (c) and (f) of Fig. **5** show that the price of investment goods drops with consumption TFP volatility, due to lower demand for investment goods (as the household is more impatience), and rises with investment TFP volatility, due to higher demand (as the household desires to save more). Sticky prices amplify the magnitude of investment price's impulse response to consumption TFP volatility. This happens as the price of investment goods is inversely related to the markup of the consumption sector, and this markup rises with consumption TFP volatility.[21] A similar pattern arises for wages.[22]

The volatility feedback is not qualitatively material for the macro impulse responses. Fig. OA.1.6 in the Online Appendix presents impulse responses in a model that excludes the feedback (that is, $\tau = 0$). Though the magnitude of the graphs changes in comparison to the benchmark case, all responses closely track the benchmark plots, featuring an identical sign. The feedback amplifies the positive effect of investment TFP volatility on future consumption. This helps explaining some asset pricing moments, as discussed in Section 5.3.

5.3. Sectoral shocks and asset-pricing implications

This section examines the impact of sectoral shocks on asset prices in the model. The model rationalizes the signs of the market prices of risk and of firms' betas to the different sources of risk. The returns for consumption and investment firms, and for the market, are defined as

$$r_{c,t+1} = \log\left(\frac{V_{c,t+1}}{V_{c,t} - d_{c,t}}\right); \quad r_{i,t+1} = \log\left(\frac{V_{i,t+1}}{V_{i,t} - d_{i,t}}\right), \quad r_{m,t+1} = \log\left(\frac{V_{m,t+1}}{V_{m,t} - d_{c,t} - d_{i,t}}\right), \tag{18}$$

where $V_{j,t}$ is the cum-dividend real market firm values, defined in Eq. (A.12), for $j \in \{c, i\}$. The aggregate market value is defined as $V_{m,t} = V_{c,t} + V_{i,t}$.

In Panel B of Table **11**, I show the model's annualized moments of the equity premium and the real risk-free rate. I multiply the model-implied market return by a factor of 5/3 to account for the fact that model firms are unlevered. For the most part, the data moments fall in the model's 90% confidence intervals. The model's equity premium is 6.6%, while it is 6.20% in the data. The volatility of the equity premium is smaller compared to the data. This is quite standard in production models and can be attributed to wages sharing a high correlation with output (see Favilukis

[21] With sticky prices, the supply of investment goods increases in response to consumption TFP volatility, while the demand for these goods drops by higher impatience. The increased supply amplifies the decline in investment price, compared to the perfect competition case.

[22] Fig. OA.1.4 in the Online Appendix plots the impulse responses of sectoral first-moment TFP innovations to detrended consumption, investment expenditures, and output. Panels (a)-(c) show that consumption TFP's impact on these quantities is positive but revert to zero shortly afterwards. Consumption TFP raises consumption by construction and raises investment expenditures as it rescales positively the relative price of investment. All responses are short lived. By contrast, investment TFP's impact is very persistent. Panels (d)-(f) show that investment TFP raises investment, as the investment sector becomes more productive. It drops consumption, as resources are allocated to the investment sector. Output's response is mixed: positive contemporaneously, but negative predictively, as is also the case in the data.

and Lin, 2016) and to the high value of γ. The real risk-free rate in the model is 1.37%, while the data counterpart is slightly below 1%. The upper bound of the model-implied 90% confidence interval for the risk-free rate volatility is close to the empirical counterpart. The autocorrelation of the risk-free rate closely matches the data.

Two channels contribute to the model's ability to obtain a high equity premium. First, a nontrivial contribution to the premium (about 15%) stems from consumption TFP risk. It is nonnegligible because of a reliance on a relatively high γ value of 25. While this value is large compared to other studies, it is in line with estimated risk aversion at quarterly frequency (see, e.g., Bansal and Shaliastovich, 2013; Van Binsbergen et al., 2012). One could obtain a considerable premium from consumption TFP risk using a lower value for γ by introducing a persistent shock to the sectoral TFP growths (see, e.g., Croce, 2014) or a labor leverage (see, e.g., Favilukis and Lin, 2016). I explore such a model extension, which relies on lower risk aversion, in the Online Appendix.

Second, a significant contribution to the equity premium (about 85%) stems from volatility risks premia. In endowment based economies with recursive preferences (e.g., long-run risk, Bansal and Yaron, 2004), stochastic volatility contributes positively to the equity premium. This notion is normally broken in general equilibrium models. As shown in Croce (2014), in a one-sector growth model with perfect competition, stochastic volatility of productivity bears a negative risk premium. This is because volatility risk is associated with bad states, and thus has a negative market price of risk while it encourages more savings, and thus has a positive market beta. By contrast, as explained next is Sections 5.3.1 and 5.3.2, in the model of this study, for each sectoral volatility, the sign of its market price of risk and its market beta is the same. The market price of risk and market exposure to consumption (investment) TFP volatility are both negative (positive). Given this outcome, along with the fact that the volatilities are persistent, and preferences are Epstein and Zin (1989), the contribution of the sectoral volatility risks to the equity premium turns positive and quantitatively large.

Allowing for market prices and betas to (potentially) time vary, and using a log-linear approximation for the log stochastic discount factor (SDF) and log-returns (as in the empirical section), the innovation to the real log-SDF ($m_{t,t+1}$), and real log-return of asset $k \in \{c, i, m\}$, ($r_{k,t+1}$), are given by

$$m_{t,t+1} - E_t m_{t,t+1} = -\lambda_{zc,t}\sigma_{zc,t}\varepsilon_{c,t+1} - \lambda_{zi,t}\sigma_{zi,t}\varepsilon_{i,t+1} - \lambda_{\sigma,zc,t}\sigma_{w,c}\varepsilon_{\sigma,c,t+1} - \lambda_{\sigma,zi,t}\sigma_{w,i}\varepsilon_{\sigma,i,t+1}; \tag{19}$$

$$r_{k,t+1} - E_t r_{k,t+1} = \beta_{k,zc,t}\sigma_{zc,t}\varepsilon_{c,t+1} + \beta_{k,zi,t}\sigma_{zi,t}\varepsilon_{i,t+1} + \beta_{k,\sigma,zc,t}\sigma_{w,c}\varepsilon_{\sigma,c,t+1} + \beta_{k,\sigma,zi,t}\sigma_{w,i}\varepsilon_{\sigma,i,t+1}, \tag{20}$$

where all shocks are defined in Appendix A, and where $\lambda_{\mathbf{t}} = [\lambda_{zc,t}, \lambda_{zi,t}, \lambda_{\sigma,zc,t}, \lambda_{\sigma,zi,t}]'$ is the vector of market prices of risk, and $\beta_{\mathbf{k,t}} = [\beta_{k,zc,t}, \beta_{k,zi,t}, \beta_{k,\sigma,zc,t}, \beta_{k,\sigma,zi,t}]'$ is the vector of risk exposures of asset k, to consumption and investment TFP, and to consumption and investment TFP volatility risks, respectively. Consider a projection of simulated paths of SDF and returns, on paths of simulated shocks:

$$m_{t,t+1} = m_0 + \tilde{\lambda}_{zc}\varepsilon_{c,t+1} + \tilde{\lambda}_{zi}\varepsilon_{i,t+1} + \tilde{\lambda}_{\sigma,zc}\varepsilon_{\sigma,c,t+1} + \tilde{\lambda}_{\sigma,zi}\varepsilon_{\sigma,i,t+1} + error; \tag{21}$$

$$r_{k,t+1} = r_{k,0} + \tilde{\beta}_{k,zc}\varepsilon_{c,t+1} + \tilde{\beta}_{k,zi}\varepsilon_{i,t+1} + \tilde{\beta}_{k,\sigma,zc}\varepsilon_{\sigma,c,t+1} + \tilde{\beta}_{k,\sigma,zi}\varepsilon_{\sigma,i,t+1} + error. \tag{22}$$

From identities (19) and (20), I define the model-implied average market prices of risk as the negative of the factor loadings of projection (21) dividend by the average quantity of risks that corresponds to each shock. The average exposures of asset k are the factor loadings of projection (22) dividend by the average quantity of risk for each shock:

$$\lambda = \left[-\frac{1}{\sigma_{zc,0}}\tilde{\lambda}_{zc},\ -\frac{1}{\sigma_{zi,0}}\tilde{\lambda}_{zi},\ -\frac{1}{\sigma_{w,c}}\tilde{\lambda}_{\sigma,zc},\ -\frac{1}{\sigma_{w,i}}\tilde{\lambda}_{\sigma,zi}\right]'; \quad \beta_k \quad = \left[\frac{1}{\sigma_{zc,0}}\tilde{\beta}_{k,zc},\ \frac{1}{\sigma_{zi,0}}\tilde{\beta}_{k,zi},\ \frac{1}{\sigma_{w,c}}\tilde{\beta}_{k,\sigma,zc},\ \frac{1}{\sigma_{w,i}}\tilde{\beta}_{k,\sigma,zi}\right]'. \tag{23}$$

I simulate population paths of the (log) SDF and returns to perform projections (21) and (22). The model-implied market prices and exposures are reported in Table **12** for two calibrations: (1) the benchmark, in Panel A; (2) a simple model with perfect competition ($\mu_j \to \infty, \quad j \in \{c, i\}$), no sticky prices, and no volatility feedback ($\tau = 0$), in Panel B.

5.3.1. Risk exposures implications

Panel A of Table **12** shows the risk exposures (betas) in the benchmark model. The exposures of the market, and of consumption and investment firms to the sectoral shocks, are qualitatively consistent with the empirical findings. Assets have a positive exposure to consumption TFP and investment TFP volatility, and a negative exposure to investment TFP and consumption TFP volatility.[23] Panel B of Table **12** shows the betas in a simplified framework in which firms are perfectly competitive. The signs of the exposures are unaltered.

The intuition behind the signs of the volatility exposures is explained in Section 4.2.2. Consumption TFP volatility causes the household to be more impatient. This lowers the demand for investment goods, causing their price to drop, and depreciates the value of installed capital of firms. A reduction in the firms' value implies a negative exposure to consumption TFP volatility ($\beta_{j,\text{C-TFP-VOL}} < 0, \quad j \in \{c, i, m\}$). By contrast, investment TFP volatility raises the incentive of the household to save. In turn, it increases the demand for investment goods and appreciates the price of (new or installed) capital. Thus, firms are positively exposed to investment TFP volatility ($\beta_{j,\text{I-TFP-VOL}} > 0, \quad j \in \{c, i, m\}$).

The exposures' signs to first-moment TFP innovations are also rationalized through their impact on the relative price of investment. Investment TFP innovation increases the supply of investment goods and drops their price. A decline in the price of capital has a negative impact on firms' valuations, which implies negative exposures to investment TFP ($\beta_{j,\text{I-TFP}} < 0, \quad j \in \{c, i, m\}$). A positive consumption TFP innovation increases the productivity of consumption firms, causing an increase in the demand for new capital goods, and increases their price. The marginal value of firms' installed capital appreciates, suggesting positive exposures to consumption TFP ($\beta_{j,\text{C-TFP}} > 0, \quad j \in \{c, i, m\}$). Panel B shows that neither monopolistic competition, nor a volatility feedback, are necessary to rationalize the empirical betas' signs.

[23] The magnitude of the model-implied risk exposures is quite different than those reported in the data (see Table **7**). This is largely because the regressors in projection (22) are the true model first- and second-moment shocks, and those are measured differently than the their empirical proxies. To bridge the gap, I construct first- and second-moment TFP shocks from simulated model sample in an identical fashion to their empirical construction. I replace the shocks in projection (22) by the empirically equivalent model-implied shocks. The obtained market exposures are 0.56, -0.16, -0.002, and 0.008 to consumption and investment TFP innovations and to consumption and investment TFP volatility risks, respectively. These are much closer in their order to the data yet still smaller due to the low return volatility in the model.

5.3.2. Market prices of risk implications

Panel A of Table **12** shows that the benchmark model explains the signs of the empirical market prices of risk for all sectoral shocks: positive for consumption TFP, investment TFP, and investment TFP volatility, and negative for consumption TFP volatility.[24] As shown in Appendix A, the real SDF is given by

$$M_{t,t+1} = \beta \left(\frac{C_{t+1}}{C_t} \right)^{-1/\psi} \left(\frac{1 - \xi N_{t+1}^{\eta}}{1 - \xi N_t^{\eta}} \right)^{1-1/\psi} \left(\frac{U_{t+1}}{\left(E_t U_{t+1}^{1-\gamma} \right)^{\frac{1}{1-\gamma}}} \right)^{1/\psi - \gamma}. \tag{24}$$

Under early resolution of uncertainty ($\gamma > \frac{1}{\psi}$), the SDF $M_{t-1,t}$, falls under three scenarios: (i) consumption C_t rises; (ii) the continuation utility U_t rises; (iii) labor N_t rises. Quantitatively, channels (i) and (ii) dominate (iii). Consequently, I analyze the impact of shocks on the SDF through their effect on immediate consumption and the continuation utility.

Consumption TFP innovation raises consumption and the continuation utility. This yields a positive market price of risk for consumption TFP innovations, as in the data. When investment TFP rises, labor flows to the investment sector, as it becomes more productive. The immediate impact on consumption is negative. If preferences excluded the impact of the continuation utility (i.e., power utility), this would imply a negative market price for investment TFP. However, as resources are shifted to the investment sector, the economy builds up more capital. This raises future consumption and the continuation utility. The rise in the continuation utility is sufficiently strong to compensate for the immediate decline in consumption. Consequently, investment TFP innovations are priced positively, as in the data. Panel B of Table **12** shows the market prices of risk in the simplified model in which firms are perfectly competitive, and that excludes the volatility feedback. The signs of the market prices of consumption TFP and investment TFP innovations are still positive.

As in the data, the market price of risk of consumption TFP volatility is negative, both in the benchmark model (Panel A) and in a perfect-competition model (Panel B). When consumption TFP volatility rises, consumption drops both contemporaneously and predictively. Future consumption profile also becomes more volatile. As the agent dislikes uncertainty, the continuation utility drops. This increases the SDF and yields a negative market price for consumption TFP volatility. Without sticky prices, consumption TFP volatility counterfactually raises consumption in short horizons. Under constant relative risk aversion (CRRA) preferences, this implies a counterfactual positive market price of risk. Under Epstein and Zin (1989) preferences, and without sticky prices, the market price is negative through the impact of higher uncertainty on the continuation utility but slightly smaller in magnitude compared to the benchmark.

By contrast, investment TFP volatility has two opposite impacts on the SDF: (a) higher investment TFP volatility drops immediate consumption and generates a more volatile consumption profile in the future that lowers the

[24]The model-implied market prices of risk do not have a quantitative empirical equivalent. This is because the model-implied market prices are derived from projection (21), while the empirical ones are constructed from a Fama-Macbeth procedure using a cross-section of assets. The empirical Fama-Macbeth method cannot be replicated in the model, as there is no firm-level heterogeneity to allow for a construction of a cross-section. As such, the model-implied market prices of risk should be compared qualitatively to the data.

continuation utility (investment TFP volatility shocks are capital-embodied shocks that affect the volatility of capital allocations in the consumption sector); (b) higher investment TFP volatility increases future consumption due to capital buildup (see Panel D of Fig. **4**). Higher future consumption can operate to raise the continuation utility. Under a reasonable calibration for macroeconomic moments, and in the absence of a volatility feedback, I find that channel (a) dominates. Consequently, the market price of risk of investment TFP volatility in Panel B is counterfactually negative. Once the empirically borne volatility feedback is added to the model ($\tau > 0$), Panel A of Table **12** shows that in the benchmark model the market price of investment TFP volatility turns positive. This is in line with the empirical findings. Intuitively, a positive feedback from investment TFP volatility to future consumption TFP strengthens quantitatively channel (b). When channel (b) dominates, investment TFP volatility is positively priced. Overall, in the benchmark model, investment TFP volatility has a prolonged impact through capital buildup, which leads to a consumption overshoot. This capital buildup happens both because investment TFP volatility induces precautionary savings and because of the volatility feedback. One may view the volatility feedback in reduced form as the effect of uncertainty on growth options in the investment sector that spurs more innovation (see Section 3.6).

5.4. Sensitivity analysis

Section OA.1.5 in the Online Appendix reports sensitivity analysis to key model parameters. When the IES parameter is greater than one, as in the benchmark calibration, the volatilities have a differential impact, consistent with the data. By contrast, when the IES is less than one, the impact of either consumption TFP volatility or investment TFP volatility on macro quantities is qualitatively similar. This happens as consumption TFP volatility increases the agent's patience, which induces higher investment, similar to investment TFP volatility. While the price rigidity ϕ_P in the benchmark calibration is large, a model that features lower price stickiness can still explain the negative effect of consumption TFP volatility on consumption. Reducing this parameter to 50, consumption and investment still drop in response to higher consumption TFP volatility. However, the IRFs are muted in absolute value compared to the benchmark. Similarly, when markups are reduced to 20%, consumption's impulse response is consistent with the data yet slightly weaker than the benchmark. When the risk aversion γ is lowered to ten, the IRFs have the same sign as in the benchmark case. The equity premium is smaller and amounts to 1.6% per annum. The betas and market prices of risk for all shocks have the same sign as their empirical counterparts. In Online Appendix OA.2, I extend the benchmark model to include a persistent component in TFPs' growth (similar to Croce, 2014). This allows to obtain a large equity premium with $\gamma = 10$, keeping other model results largely unchanged. Lastly, I introduce a positive correlation between the sectoral volatility shocks. As the two volatilities affect consumption oppositely, they partly offset each other, yet all IRFs, market prices of risk, and exposures maintain their correct sign. Section OA.1.4 provides additional discussion on how the correlation between the volatilities affects the results.

6. Conclusion

In this paper, I empirically show a novel empirical challenge: consumption sector's technological volatility and investment sector's technological volatility oppositely interact with economic growth, aggregate asset prices, and the cross-section of returns. I develop a general equilibrium two-sector model that rationalizes the opposite roles of the sectoral volatilities.

On the macroeconomic front, the paper overturns the common negative empirical interaction of volatility with the real economy. While consumption TFP volatility inhibits investment, consumption, output, and wages, investment TFP volatility stimulates these variables. The positive impact of investment TFP volatility on investment is explained via precautionary-saving channel. The contractionary impact of consumption TFP volatility on investment hinges on the agent's preferences. Under early resolution of uncertainty, the agent hedges against consumption sector's volatility by shifting her consumption profile to the present and investing less. Higher consumption TFP volatility is equivalent to a time-preference shock, which makes the agent more impatient, thus discouraging investment.

On the asset-pricing front, I find that a production pricing kernel that excludes the sectoral volatilities is misspecified. The misspecification is important, as TFP volatilities improve the factor model's fit to the data, beyond first-moment innovations. The sectoral volatility risks have market prices of risk of opposite signs, and they impact stock prices oppositely. Investment (consumption) TFP volatility increases (lowers) equity valuations, empirically and in the model, as it increases (decreases) the demand for capital goods and appreciates (depreciates) installed capital's value. Both volatility shocks contribute positively to the equity premium, a nonstandard feature of general equilibrium models.

In all, the theoretical and empirical evidence shows the importance of separate fluctuations in sectoral volatilities for growth and prices. Future research can model policies designed to curb uncertainty and examine their effectiveness when volatility stems from the investment sector versus the consumption sector. Another avenue is to allow for firm-level heterogeneity to endogenize the risk exposures to volatility shocks in the cross-section.

Appendix A. The model details

A.1. Aggregation

The aggregator in the consumption (investment) sector produces composite or "final" consumption (investment) goods, denoted $Y_{c,t}$ ($Y_{i,t}$). $Y_{c,t}$ will be used for consumption by the household, while $Y_{i,t}$ will be equal to aggregate investment goods in the economy. Production of the composite consumption (investment) good requires a continuum of differentiated intermediate goods as inputs, denoted by $\{y_{c,t}(n)\}_{\{n\in[0,1]\}}$ ($\{y_{i,t}(n)\}_{\{n\in[0,1]\}}$). The aggregation technology in both sectors is symmetric, so I describe it jointly. The production of the composite good $Y_{j,t}$, in sector $j \in \{c, i\}$, converts the sector's intermediate goods into a final good using a constant elasticity of substitution (CES) technology:

$$Y_{j,t} = \left[\int_0^1 (y_{j,t}(n))^{\frac{\mu_j - 1}{\mu_j}} dn \right]^{\frac{\mu_j}{\mu_j - 1}}, \quad j \in \{c, i\}. \tag{A.1}$$

The parameter $\mu_j, \quad j \in \{c, i\}$, controls the substitutability among the intermediate goods. Perfect competition between the intermediate good producers requires $\mu_j \to \infty$. When μ_j is finite, the intermediate goods in sector j are not perfect substitutes, and thus each intermediate good producer has some degree of monopolistic power. Each final good producer (aggregator) in sector j sells its output $Y_{j,t}$ at nominal price $P_{j,t}$. Each intermediate good producer sells its intermediate good to the aggregator at a nominal price $p_{j,t}(n)$. The aggregator in each sector $j \in \{c, i\}$ faces perfectly competitive market, thus solving

$$\max_{\{y_{j,t}(n)\}} P_{j,t} Y_{j,t} - \int_0^1 p_{j,t}(n) y_{j,t}(n) dn, \quad j \in \{c, i\}, \tag{A.2}$$

where $Y_{j,t}$ is given by Eq. (A.1), and the prices are taken as given. The first-order condition of Eq. (A.2) yields the demand for differentiated intermediate good of type n in sector j:

$$y_{j,t}(n) = \left[\frac{p_{j,t}(n)}{P_{j,t}} \right]^{-\mu_j} Y_{j,t}, \quad j \in \{c, i\}. \tag{A.3}$$

As the market for final goods is perfectly competitive, the final good producing firm (aggregator) in sector j earns zero profits in equilibrium. This condition, along with Eq. (A.2) and (A.3), yields the aggregate price index in sector j, given by

$$P_{j,t} = \left[\int_0^1 (p_{j,t}(n))^{1-\mu_j} dn \right]^{\frac{1}{1-\mu_j}}, \quad j \in \{c, i\}. \tag{A.4}$$

A.2. Intermediate good production

A.2.1. Sectoral intermediate good producers

This section describes the production of intermediate goods. Since the description of production in the consumption sector and investment sector is symmetric, I describe them jointly.

Intermediate goods in sector $j \in \{c, i\}$ are differentiated, and each type is denoted by $n \in [0, 1]$. Each intermediate good producer n in sector j rents labor $n_{j,t}(n)$ from the household and owns capital stock $k_{j,t}(n)$. The intermediate good producer n in sector j produces an intermediate good $y_{j,t}(n)$, using a constant returns-to-scale Cobb-Douglas production function over capital and labor and subject to sectoral TFP shocks $Z_{j,t}$:

$$y_{j,t}(n) = Z_{j,t} k_{j,t}(n)^{\alpha_j} n_{j,t}(n)^{1-\alpha_j}, \quad j \in \{c, i\}, \tag{A.5}$$

where α_j is the capital share of output of intermediaries in sector j, and $Z_{j,t}, \quad j \in \{c, i\}$, are the sectoral TFPs. Each intermediate good producer who wishes to invest an amount $i_{j,t}(n)k_{j,t}(n)$, where $i_{j,t}(n)$ is the investment rate, must purchase $\Phi_k(i_{j,t}(n))k_{j,t}(n)$ units of capital goods under an equilibrium price of investment goods $P_{i,t}$. The convex adjustment cost function $\Phi_k(i)$ is given by

$$\Phi_k(i) = \frac{1}{\phi}(1+i)^{\phi} - \frac{1}{\phi}. \tag{A.6}$$

Capital of each producer of type n in sector j depreciates at rate δ and evolves as:

$$k_{j,t+1}(n) = (1 - \delta + i_{j,t}(n))k_{j,t}(n). \tag{A.7}$$

Intermediate good producers in both sectors are monopolistic competitors in the product market and price takers in the input market. They face a quadratic costs of changing their nominal output price $p_{j,t}(n)$ each period, similar to Rotemberg (1982), given by

$$\Phi_{P,j}(p_{j,t}(n), p_{j,t-1}(n)) = \frac{\phi_{P,j}}{2}\left[\frac{p_{j,t}(n)}{\Pi_j p_{j,t-1}(n)} - 1\right]^2 p_{j,t-1}(n)Y_{j,t}, \quad j \in \{c, i\}, \tag{A.8}$$

where $Y_{j,t}$ is the final composite good in sector j, Π_j is the steady state inflation in the j sector, and $\phi_{P,j}$ governs the degree of price rigidity in sector j. In all, the period nominal dividend of intermediate good producer of type n in sector j, $d^{\$}_{j,t}(n)$, in terms on nominal consumption goods, is given by

$$d^{\$}_{j,t}(n) = p_{j,t}(n)y_{j,t}(n) - W_t n_{j,t}(n) - P_{i,t}\Phi_k(i_{j,t}(n))k_{j,t}(n) - \Phi_{P,j}(p_{j,t}(n), p_{j,t-1}(n)), \quad j \in \{c, i\}. \tag{A.9}$$

Each intermediate good producer n chooses optimal hiring, investment, and nominal output price to maximize the firm's market value, taking as given nominal wages W_t, the nominal price of investment goods $P_{i,t}$, the demand for differentiated intermediate good n in sector j given by Eq. (A.3), and the nominal stochastic discount factor of the household $M^{\$}_{t,t+1}$. Specifically, the intermediate good producers maximize

$$V^{\$}_{j,t}(n) = \max_{\{n_{j,s}(n), k_{j,s}(n), p_{j,s}(n)\}} \quad E_t \Sigma_{s=t}^{\infty} M^{\$}_{t,t+s} d^{\$}_{j,t+s}(n), \tag{A.10}$$

subject to Eq. (A.7), Eq. (A.9), and the demand constraint

$$\left[\frac{p_{j,t}(n)}{P_{j,t}}\right]^{-\mu_j} Y_{j,t} \leq Z_{j,t}k_{j,t}(n)^{\alpha_j} n_{j,t}(n)^{1-\alpha_j}, \quad j \in \{c, i\}. \tag{A.11}$$

Notice that $V^{\$}_{j,t}(n), \quad j \in \{i, c\}$, is in nominal consumption units. Define the real firm value $V_{j,t}(n)$ and real dividend $d_{j,t}(n)$ (in terms of real consumption goods) by

$$V_{j,t}(n) = V^{\$}_{j,t}(n)/P_{c,t}; \quad d_{j,t}(n) = d^{\$}_{j,t}(n)/P_{c,t}. \tag{A.12}$$

Lastly, define the real growth rate in aggregate investment expenditures (in terms of real consumption goods) as $\Delta I_t = \frac{(P_{i,t}/P_{c,t})Y_{i,t}}{(P_{i,t-1}/P_{c,t-1})Y_{i,t-1}}$ and the growth rate in the relative price of investment goods by $\Delta P_{i,t} = \frac{P_{i,t}/P_{c,t}}{P_{i,t-1}/P_{c,t-1}}$.

A.2.2. Productivity shocks

The production in the investment sector is subject to a sectoral TFP shock, denoted $Z_{i,t}$, and similarly, the production in the consumption sector is subject to a sectoral TFP shock, denoted $Z_{c,t}$. The sectoral TFP growth rates are characterized as follows:

$$\frac{Z_{i,t}}{Z_{i,t-1}} = \mu_{z,i} + \tilde{\varepsilon}_{i,t}, \tag{A.13}$$

$$\frac{Z_{c,t}}{Z_{c,t-1}} = \mu_{z,c} + \tilde{\varepsilon}_{c,t}, \tag{A.14}$$

where $\tilde{\varepsilon}_{i,t} = \sigma_{zi,t-1}\varepsilon_{i,t}$, and $\tilde{\varepsilon}_{c,t} = \tau(\sigma^2_{zi,t-1} - \sigma^2_{zi,0}) + \sigma_{zc,t-1}\varepsilon_{c,t}$. The shocks $\varepsilon_{i,t}$ and $\varepsilon_{c,t}$ are orthogonal and are independent and identically distributed (i.i.d.) standard normal.[25] Driven by the empirical findings of Section 3.6, Eq. (A.14) shows that I incorporate a positive volatility feedback from investment-technology volatility, $\sigma^2_{zi,t-1}$ to one-period-ahead consumption TFP growth, which is governed by the parameter $\tau > 0$. The processes $\sigma_{zc,t}$ and $\sigma_{zi,t}$ capture time variation in the volatility of sectoral growth shocks. They follow independent AR(1) processes

$$\sigma^2_{zi,t} = (1 - \rho_{\sigma,zi})\sigma^2_{zi,0} + \rho_{\sigma,zi}\sigma^2_{zi,t-1} + \sigma_{w,i}\varepsilon_{\sigma,i,t}, \tag{A.15}$$

$$\sigma^2_{zc,t} = (1 - \rho_{\sigma,zc})\sigma^2_{zc,0} + \rho_{\sigma,zc}\sigma^2_{zc,t-1} + \sigma_{w,c}\varepsilon_{\sigma,c,t}, \tag{A.16}$$

where the volatility shocks $\varepsilon_{\sigma,i,t}$ and $\varepsilon_{\sigma,c,t}$ are i.i.d. over time and are standard normal.

A.3. Household

The economy is populated by a representative household that supplies total labor N_t, which flows to the both sectors. It derives utility from an Epstein and Zin (1989) and Weil (1989) utility over a stream of consumption goods C_t and disutility from labor N_t:

$$U_t = \left\{(1-\beta)\left[C_t(1-\xi N_t^{\eta})\right]^{1-1/\psi} + \beta\left(E_t U_{t+1}^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\right\}^{\frac{1}{1-1/\psi}}, \tag{A.17}$$

where β is the time discount rate, γ is the relative risk aversion, ψ is the IES, ξ is the amount of disutility from labor, and η is the sensitivity of disutility to working hours. When $\gamma > (<)\frac{1}{\psi}$, the household has preferences exhibiting early (late) resolution of uncertainty. The household derives income from labor and from the dividends of intermediate

[25]Notice that I do not exponentiate the right-hand side of the sectoral growth rates in Eq. (A.13), and (A.14). Thus, TFP growth rates are normal instead of log-normal. The motivation for this modeling choice is to exclude any hardwired Jensen effect that can mechanically yield an impact of volatility on the mean growth rate. The parameters μ_{zc} and μ_{zi} are set to values above one, while the shocks are small, ensuring the growth rate is never negative in any population simulation. However, exponentiating the growth rates to ensure positivity does not change the qualitative or quantitative results of this paper.

consumption and investment good producers. She chooses labor supply and consumption to maximize her lifetime utility, subject to the budget constraint:[26]

$$\max_{\{C_s,N_s\}} \quad U_t, \quad \text{s.t. } P_{c,t}C_t = W_tN_t + \int_0^1 d^{\$}_{c,t}(n)dn + \int_0^1 d^{\$}_{i,t}(n)dn, \tag{A.18}$$

where $P_{c,t}$ is the nominal price of final consumption goods, and W_t is the nominal market wage. From the consumer problem, I can obtain the nominal SDF used to discount the nominal dividend of intermediate good producing firms in both sectors:

$$M^{\$}_{t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-1/\psi}\left(\frac{1-\xi N^{\eta}_{t+1}}{1-\xi N^{\eta}_t}\right)^{1-1/\psi}\left(\frac{U_{t+1}}{\left(E_tU^{1-\gamma}_{t+1}\right)^{\frac{1}{1-\gamma}}}\right)^{1/\psi-\gamma}\frac{P_{c,t}}{P_{c,t+1}}. \tag{A.19}$$

A.4. Monetary authority

A monetary authority sets the nominal log-interest rate $r^{\$}_t$ according to a Taylor (1993) rule:

$$r^{\$}_t = \rho_r r^{\$}_{t-1} + (1-\rho_r)(r^{\$}_{ss} + \rho_\pi(\pi_t - \pi_{ss}) + \rho_y(\Delta y_t - \Delta y_{ss})), \tag{A.20}$$

where π_t is log inflation (in the consumption sector) defined as $\pi_t = \log\left(\frac{P_{c,t}}{P_{c,t-1}}\right)$, and Δy_t is log-growth of real total output, $\Delta y_t = \log\left(\frac{Y_{c,t}+P_{i,t}/P_{c,t}Y_{i,t}}{Y_{c,t-1}+P_{i,t-1}/P_{c,t-1}Y_{i,t-1}}\right)$. $r^{\$}_{ss}$, π_{ss}, and Δy_{ss} are the steady state log-levels of nominal interest rate, inflation, and output growth.

A.5. Equilibrium

In equilibrium, W_t, $P_{i,t}$, and π_t are set to clear all markets:

- Labor market clearing: $$\int_0^1 n_{c,t}(n)dn + \int_0^1 n_{i,t}(n)dn = N_t. \tag{A.21}$$
- Consumption good market clearing: $$C_t = Y_{c,t}. \tag{A.22}$$
- Investment good clearing: $$\int_0^1 \Phi_k(i_{c,t}(n))K_{c,t}(n)dn + \int_0^1 \Phi_k(i_{i,t}(n))K_{i,t}(n)dn = Y_{i,t}. \tag{A.23}$$
- Zero net supply of nominal bonds: $$\frac{1}{R^{\$}_t} = E_t[M^{\$}_{t+1}] \tag{A.24}$$

An equilibrium consists of prices and allocations s.t. taking prices as given, (i) household's allocation solves Eq. (A.18); (ii) firms' allocations solve Eq. (A.10); (iii) labor, consumption good, investment good and bond markets clear. I solve for a symmetric equilibrium in which intermediate good firms in both sectors employ the same amount $n_{j,t}(n) = n_{j,t}$, choose to hold the same amount of capital $k_{j,t}(n) = k_{j,t}$, and select the same price $P_{j,t}(n) = P_{j,t}$.

[26]This is a simplified budget constraint. I implicitly imposed the market-clearing condition that the nominal bond holding of the household is zero every period ($B_t = B_{t+1} = 0$), and the household is the owner of all shares for all firms ($\omega_{j,t}(n) = \omega_{j,t+1}(n) = 1, \quad j \in \{i, c\}, n \in [0, 1]$, where $\omega_{j,t}(n)$ is the fraction of firm n in sector j held by the household).

Appendix B. Calibration

Table B.1 shows the parameter choices of the model in the benchmark case. The model is calibrated at quarterly frequency. There are three main parameter groups.

Table B.1

Calibration of the benchmark model

The table presents parameter choice of the model parameters in the benchmark case.

Symbol	Value	Parameter
γ	25	Relative risk aversion
ψ	1.7	Intertemporal elasticity of substitution
β	0.997	Time discount factor
ξ	3	Disutility from labor
η	1.4	Sensitivity of disutility to working hours
$\alpha_c = \alpha_i$	0.33	Share of capital in output
δ	0.015	Depreciation rate
μ_{zc}	1.0024	Drift of consumption sector TFP
μ_{zi}	1.0050	Drift of investment sector TFP
$\sigma_{zc,0}$	0.01	Unconditional volatility of consumption TFP shock
$\sigma_{zi,0}$	0.02	Unconditional volatility of investment TFP shock
ρ_σ	0.95	Persistence of volatilities
μ_c	4	Markup of 25% in the consumption sector
μ_i	4	Markup of 25% in the investment sector
ϕ_P	250	Rotemberg price rigidity
π_{ss}	0.005	Steady state inflation
ρ_π	1.5	Weight on inflation gap in Taylor rule
ρ_y	0.5	Weight on output gap in Taylor rule
τ	15	Feedback from investment TFP volatility to future consumption TFP

Production and technology parameters. I set $\alpha_i = \alpha_c = 0.33$ so that the labor share in each sector is about 2/3. The quarterly depreciation rate is 0.015, which implies annual depreciation of 6%. Closely to Papanikolaou (2011), the capital adjustment cost parameter is $\phi = 1.2$. I set the growth rates of the sectoral TFPs, μ_{zc} and μ_{zi}, to values that are close to the empirical estimates of Fernald (2012). These growth rates pin down the model-implied growth rates of consumption and of the relative price of investment goods. The steady state growth rate of per-capita consumption is about 2% per annum. The unconditional volatilities of the sectoral TFP shocks $\sigma_{zc,0}$ and $\sigma_{zi,0}$ are also close to the empirical estimates of Fernald (2012). They are set to match the volatility of consumption growth and investment growth. Investment TFP exhibits larger drift and volatility compared to consumption TFP. The persistence of the stochastic volatility in both sectors ρ_σ is set to 0.95, which falls in the 90% confidence interval for the auto-correlation of sectoral realized variations. This value is higher than Basu and Bundick (2017) but smaller than the estimated volatility persistence of Bansal and Shaliastovich (2013). The standard deviation of the volatility shock in each sector is set such that the ratio between the variance of the sectoral volatility process to its unconditional mean is similar to the empirical counterpart (thus, I use $\sigma_{w,i} = 6.02 \cdot 10^{-5}$ and $\sigma_{w,c} = 1.50 \cdot 10^{-5}$). The feedback from investment TFP volatility to one quarter ahead consumption TFP growth is $\tau = 15$. This parameter governs the magnitude of the slope coefficient of investment TFP volatility in a regression of one-period-ahead consumption TFP growth on the lagged values of the sectoral TFP growth rates and the sectoral volatilities (in a similar fashion to the projection of Table **10**). Under the calibrated τ parameter, the slope coefficient of investment TFP volatility falls in the 90% confidence interval of its empirical counterpart.[27]

Preference parameters. The time discount factor is $\beta = 0.997$, consistent with the value used in both Liu, Fernald, and Basu (2012) and Garlappi and Song (2017), and allows to closely match the level of the real risk-free rate. The relative risk aversion γ is set to 25. Though this number is quite high, it is consistent with, and even smaller than, some estimates from quarterly frequency (see, e.g., Bansal and Shaliastovich, 2013; Van Binsbergen et al., 2012; Rudebusch and Swanson, 2012). This parameter helps to target the level of the equity premium. The IES is set to 1.7, consistent with Bansal, Kiku, and Yaron (2012) and Bansal and Shaliastovich (2013). As discussed in Section 4.2.1, it is qualitatively essential to calibrate this parameter to a value that is greater than unity. The sensitivity of disutility to working hours η is set to 1.4, consistent with Jaimovich and Rebelo (2009). The degree of disutility to working hours ξ is chosen such that in the deterministic steady state, the household works roughly 20% of its time.

Nominal rigidities and monetary policy parameters. Monetary policy parameters are consistent with Basu and Bundick (2017) and are standard in the literature. I set $\rho_r = 0.5$, $\rho_\pi = 1.5$, and $\rho_\pi = 0.5$. The nominal risk-free steady state interest rate is set such that the deterministic steady state inflation rate is 0.005 per quarter, or 2% per annum. I choose market power parameters of $\mu_c = \mu_i = 4$, which implies, on average, a 25% markup for firms in both sectors, similar to Garlappi and Song (2017). The price adjustment cost parameter of consumption producing firms is set to $\phi_{P,C} = 250$ ($\equiv \phi_P$) and contributes to matching the comovement between investment and consumption.[28] This value is slightly higher, but of a similar magnitude, to the parameter used in Basu and Bundick (2017).

[27]Consider a projection of one-quarter-ahead consumption TFP growth onto standardized values of the two sectoral TFP growth rates and the two sectoral volatilities, constructed as described in Section 3.2. The loading on investment TFP volatility is 0.12 inside the model, while the empirical 90% confidence interval of this loading is [0.09,1.51].

[28]As sticky prices in the investment sector are not qualitatively significant to explain the empirical findings, I refrain from incorporating price adjustment costs in the investment sector ($\phi_{P,I} = 0$).

Appendix C. Characterization of model's solution

C.1. Equilibrium conditions

This section describes the equilibrium first-order conditions of the model described in Section 4. The first-order condition of firm $n \in [0,1]$ in sector $j \in \{c, i\}$

$$0 = q_{j,t} - P_{it}\Phi'_k(i_{j,t}(n)) \tag{C.1}$$

$$0 = W_t n_{j,t}(n) - (1-\alpha_j)\theta_{j,t} Z_{j,t} k_{j,t}(n)^{\alpha_j} n_{j,t}(n)^{1-\alpha_j} \tag{C.2}$$

$$\begin{aligned} 0 = -q_{j,t} + E_t\Big[M^{\$}_{t+1}\Big\{&-P_{i,t+1}\Phi_k(i_{j,t+1}) + q_{j,t+1}(1-\delta+i_{j,t+1}(n)) \\ &+\theta_{j,t+1}Z_{j,t+1}\alpha_j k_{j,t+1}(n)^{\alpha_j-1} n_{j,t+1}(n)^{1-\alpha_j}\Big\}\Big] \end{aligned} \tag{C.3}$$

$$\begin{aligned} 0 = (1-\mu_j)\left[\frac{p_{j,t}(n)}{P_{j,t}}\right]^{-\mu_j} + \theta_{j,t}\mu_j\left[\frac{p_{j,t}(n)}{P_{j,t}}\right]^{-\mu_j-1}\frac{1}{P_{j,t}} - \phi_P\left[\frac{p_{j,t}(n)}{\Pi_j p_{j,t-1}(n)} - 1\right]\frac{1}{\Pi_j} \\ + \phi_P E_t\left[M^{\$}_{t+1}\left(\frac{Y_{j,t+1}}{Y_{j,t}}\right)\left\{\left[\frac{p_{j,t+1}(n)}{\Pi_j p_{j,t}(n)} - 1\right]\frac{p_{j,t+1}(n)}{\Pi_j p_{j,t}(n)} - \frac{1}{2}\left[\frac{p_{j,t+1}(n)}{\Pi_j p_{j,t}(n)} - 1\right]^2\right\}\right] \end{aligned} \tag{C.4}$$

$$0 = k_{j,t+1}(n) - (1-\delta+i_{j,t}(n))k_{j,t}(n) \tag{C.5}$$

$$0 = y_{j,t}(n) - Z_{j,t}k_{j,t}(n)^{\alpha_j} n_{j,t}(n)^{1-\alpha_j}, \tag{C.6}$$

where $q_{j,t}$ is the price of a marginal unit of installed capital in sector j, the Lagrange multiplier of constraint (A.7), and $\theta_{j,t}$ is the marginal cost of producing an additional unit of intermediate good in sector $j \in \{c, i\}$, the Lagrange multiplier of constraint (A.11).

The first-order condition of the household

$$0 = \frac{W_t}{P_{c,t}} - \frac{C_t}{1-\xi N_t^{\eta}}\xi\eta N_t^{\eta-1}. \tag{C.7}$$

The nominal SDF, nominal interest rate, as well as the household utility, are given in Eq. (A.19), (A.20), and (A.17), respectively. The last equilibrium conditions include four market clearing conditions (labor, investment goods, consumption goods, and bond market) specified in Eq. (A.21), (A.22), (A.23), and (A.24), respectively. We are looking for a symmetric equilibrium in which $P_{j,t}(n) = P_{j,t}$, $n_{j,t}(n) = n_{j,t}$, and $k_{j,t}(n) = k_{j,t}$ for all $n \in [0,1]$ and $j \in \{c, i\}$. Thus, the above equations can be rewritten in terms of only aggregate quantities. There are 20 endogenous variables $\{C_t, N_t, Y_{c,t}, Y_{i,t}, N_{c,t}, N_{i,t}, K_{c,t}, K_{i,t}, i_{c,t}, i_{i,t}, q_{c,t}, q_{i,t}, \theta_{c,t}, \theta_{i,t}, P_{i,t}, P_{c,t}, W_t, R^{\$}_t, U_t, M^{\$}_t\}$. In turn, there are 20 equations: 13 equations for household's and firms' first-order conditions (in both sectors), four market clearing conditions, and three definitions of SDF, utility, and Taylor rule). Other quantities, such as the real SDF and firm valuations, are derived from the endogenous decision variables, see, e.g., Eq. (A.10).

C.2. Detrended problem

Covariance-stationary first-order conditions can be achieved by rescaling the nonstationary variables of the problem as follows: (a) divide $k_{c,t}$, $k_{i,t}$, $Y_{i,t}$ by $Z_{i,t-1}^{\frac{1}{1-\alpha_i}}$; (b) divide C_t, $Y_{c,t}$, U_t by $Z_{c,t-1}Z_{i,t-1}^{\frac{\alpha_c}{1-\alpha_i}}$; (c) divide W_t by $P_{c,t}Z_{c,t-1}Z_{i,t-1}^{\frac{\alpha_c}{1-\alpha_i}}$; (d) divide $\theta_{c,t}$ by $P_{c,t}$; (e) divide $\theta_{i,t}$, $q_{i,t}$, $q_{c,t}$, $P_{i,t}$ by $P_{c,t}Z_{c,t-1}Z_{i,t-1}^{\frac{\alpha_c-1}{1-\alpha_i}}$. After plugging the rescaled variables in the first-order equations, the equilibrium conditions can be written using stationary variables (in particular, using the rescaled variables and using the growth rates of $Z_{c,t}, Z_{i,t}$, and of $P_{c,t}$).

Appendix D. Consumption TFP as a preference shock

In this appendix, I show that the maximization programs (8) and (15) are equivalent. For notational ease, I denote the budget constraint of program (8), with the exclusion of consumption production, that is, Eq. (10)-(14), as $\{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it})$.

Define $\hat{C}_t = \frac{C_t}{z_{ct-1}}$ and $\hat{V}_t = \frac{V_t}{z_{ct-1}}$. It is straightforward to show using first-order condition equivalence that the solution to the program (8) solves the partially detrended value function given by

$$\hat{V}_t(k_{ct}, k_{it}, z_{it}, \frac{z_{ct}}{z_{ct-1}}) = \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \Bigg\{(1-\beta)\hat{C}_t^{1-1/\psi} + \beta\left(\frac{z_{ct}}{z_{ct-1}}\right)^{1-\frac{1}{\psi}}\left(E_t\hat{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1}, \frac{z_{ct+1}}{z_{ct}})^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\Bigg\}^{\frac{1}{1-1/\psi}} \tag{D.1}$$

s.t.

$$\hat{C}_t = \frac{z_{ct}}{z_{ct-1}} k_{ct}^{\alpha} n_{ct}^{1-\alpha}$$

$$\{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it})$$

$$\frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1},$$

and where $\mathbb{B}(k_{it}, k_{ct}, z_{it})$ is the same budget constraint as of program (8).

The detrended value function $\hat{V}$ of program (D.1) is homogeneous of degree one in $\frac{z_{ct}}{z_{ct-1}}$. To see this, plug the expression for $\hat{C}_t$ in the objective function to obtain

$$\hat{V}_t(k_{ct}, k_{it}, z_{it}, \frac{z_{ct}}{z_{ct-1}}) = \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \Bigg\{(1-\beta)\left(\frac{z_{ct}}{z_{ct-1}} k_{ct}^{\alpha} n_{ct}^{1-\alpha}\right)^{1-1/\psi} + \beta\left(\frac{z_{ct}}{z_{ct-1}}\right)^{1-\frac{1}{\psi}}\left(E_t\hat{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1}, \frac{z_{ct+1}}{z_{ct}})^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\Bigg\}^{\frac{1}{1-1/\psi}}$$

s.t. $\{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it})$

$$\frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1}.$$

Notice, that $\frac{z_{ct}}{z_{ct-1}}^{1-1/\psi}$ multiplies both terms inside the maximand $\{\cdot\}^{\frac{1}{1-1/\psi}}$ expression. Thus, one can rewrite the program

$$\hat{V}_t(k_{ct}, k_{it}, z_{it}, \frac{z_{ct}}{z_{ct-1}}) = \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \left(\frac{z_{ct}}{z_{ct-1}}\right) \Bigg\{(1-\beta)\left(k_{ct}^{\alpha} n_{ct}^{1-\alpha}\right)^{1-1/\psi} + \beta\left(E_t \hat{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1}, \frac{z_{ct+1}}{z_{ct}})^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\Bigg\}^{\frac{1}{1-1/\psi}} \tag{D.2}$$

$$\text{s.t. } \{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it})$$

$$\frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1}$$

For any scalar $\lambda > 0$, specification (D.2) permits the following identity:

$$\begin{aligned}
\hat{V}_t(k_{ct}, k_{it}, z_{it}, \lambda\frac{z_{ct}}{z_{ct-1}}) &= \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \lambda\left(\frac{z_{ct}}{z_{ct-1}}\right) \Bigg\{(1-\beta)\left(k_{ct}^{\alpha} n_{ct}^{1-\alpha}\right)^{1-1/\psi} \\
&\quad + \beta\left(E_t \hat{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1}, \frac{z_{ct+1}}{z_{ct}})^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\Bigg\}^{\frac{1}{1-1/\psi}} \\
&\quad \text{s.t. } \{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it}) \\
&\quad \frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1} \\
&= \lambda \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \left(\frac{z_{ct}}{z_{ct-1}}\right) \Bigg\{(1-\beta)\left(\hat{k}_{ct}^{\alpha} n_{ct}^{1-\alpha}\right)^{1-1/\psi} \\
&\quad + \beta\left(E_t \hat{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1}, \frac{z_{ct+1}}{z_{ct}})^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\Bigg\}^{\frac{1}{1-1/\psi}} \\
&\quad \text{s.t. } \{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it}) \\
&\quad \frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1} \\
&= \lambda \hat{V}_t(k_{ct}, k_{it}, z_{it}, \frac{z_{ct}}{z_{ct-1}}).
\end{aligned} \tag{D.3}$$

The second equality of Eq. (D.3) stems from the fact that λ is only a multiplicative constant that rescales the objective function but does not affect the budget constraints or the continuation value's state variables (as the growth in z_{ct} is independent over time). The third equality establishes homogeneity of degree one in consumption TFP growth. As a corollary, it is possible to write

$$\hat{V}_t(k_{ct}, k_{it}, z_{it}, \frac{z_{ct}}{z_{ct-1}}) = \left(\frac{z_{ct}}{z_{ct-1}}\right) \tilde{V}_t(k_{ct}, k_{it}, z_{it}). \tag{D.4}$$

Lastly, the ex-ante expectation of $\frac{z_{ct+1}}{z_{ct}}$ behaves like a preference shock in the problem (D.2). To see this, divide both hands of Eq. (D.2) by $\frac{z_{ct}}{z_{ct-1}}$, and use the corollary (D.4) to obtain

$$\begin{aligned}\tilde{V}_t(k_{ct}, k_{it}, z_{it}) = \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \quad & \Bigg\{(1-\beta)\left(k_{ct}^{\alpha} n_{ct}^{1-\alpha}\right)^{1-1/\psi} \\ & +\beta\left(E_t\left(\frac{z_{ct+1}}{z_{ct}}\right)^{1-\gamma}\tilde{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1})^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\Bigg\}^{\frac{1}{1-1/\psi}} \\ & \{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it}) \\ & \frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1}.\end{aligned} \tag{D.5}$$

As $\tilde{V}_{t+1}$ is independent of $\frac{z_{ct+1}}{z_{ct}}$, we can separate the expectation in the objective function of Eq. (D.5) to obtain

$$\begin{aligned}\tilde{V}_t(k_{ct}, k_{it}, z_{it}) = \max_{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}} \quad & \Bigg\{(1-\beta)\left(k_{ct}^{\alpha} n_{ct}^{1-\alpha}\right)^{1-1/\psi} \\ & +\underbrace{\beta\left(E_t\left(\frac{z_{ct+1}}{z_{ct}}\right)^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}}_{\tilde{\beta}_t}\left(E_t\tilde{V}_{t+1}(k_{ct+1}, k_{it+1}, z_{it+1})^{1-\gamma}\right)^{\frac{1-1/\psi}{1-\gamma}}\Bigg\}^{\frac{1}{1-1/\psi}} \\ & \{I_{i,t}, I_{c,t}, n_{c,t}, n_{i,t}\} \in \mathbb{B}(k_{it}, k_{ct}, z_{it}) \\ & \frac{z_{ct+1}}{z_{ct}} = \mu_{zc} + \sigma_{zc,t}\varepsilon_{zc,t+1}.\end{aligned}$$

This program is identical to that specified in Eq. (15). Thus, the solution of program (15) is identical to the solution of Eq. (D.1), which is equal to the solution of Eq. (8). When z_{ct} is a random walk, the expression $\tilde{\beta}_t$ behaves like a preference shock that depends on the conditional volatility $\sigma_{zc,t}$.

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Table 1

Summary statistics of sectoral volatilities

Panel A presents the mean, standard deviation (Std. dev.), skewness (Skew), and autocorrelation (AC(1)) for consumption TFP volatility (C-TFP-VOL) and investment TFP volatility (I-TFP-VOL). The statistics are reported for the full sample, as well as for expansion and recession periods separately. Recession dates are based on NBER. The mean and standard deviation statistics are divided by 10^{-4}. Data on sectoral volatilities are from 1949Q1-2014Q2 (first W quarters used to construct realized variances). Panel B reports the correlation between the sectoral TFP realized variations during the full sample period, expansions, and NBER recessions. 95% confidence interval are reported in brackets.

Panel A: Sector-specific statistics

	Mean	Std dev	Skew	AC(1)
Full sample:				
C-TFP-VOL	4.26	1.64	2.48	0.78
	[3.79, 4.73]	[1.51, 1.80]	[$1.33 \cdot 10^{-4}$, 2.93]	[0.70, 0.85]
I-TFP-VOL	5.14	1.55	2.41	0.75
	[4.71, 5.58]	[1.43, 1.70]	[$1.26 \cdot 10^{-4}$, 2.82]	[0.67, 0.83]
Expansions:				
C-TFP-VOL	3.93	1.24	3.16	0.72
	[3.56, 4.31]	[1.14, 1.38]	[$0.91 \cdot 10^{-4}$, 4.03]	[0.51, 0.95]
I-TFP-VOL	4.81	1.10	2.75	0.70
	[4.48, 5.14]	[1.01, 1.22]	[$0.84 \cdot 10^{-4}$, 3.50]	[0.51, 0.93]
Recessions:				
C-TFP-VOL	5.57	2.30	1.22	0.65
	[4.43, 6.70]	[1.93, 2.85]	[$1.67 \cdot 10^{-4}$, 1.70]	[0.46, 0.84]
I-TFP-VOL	6.50	2.24	1.20	0.63
	[5.40, 7.60]	[1.88, 2.78]	[$1.63 \cdot 10^{-4}$, 1.66]	[0.44, 0.82]

Panel B: Correlation between sectoral variations

	Full sample	Expansions	Recessions
	0.84	0.86	0.78
	[0.80, 0.88]	[0.82, 0.88]	[0.67, 0.86]

Table 2

Sectoral shocks and aggregate cash flow (macroeconomic) growth

The table shows the evidence from the projection of future aggregate cash flow growth rates on the current sectoral shocks: consumption TFP innovation, ΔC-TFP; investment TFP innovation, ΔI-TFP; consumption TFP volatility shock, ΔC-TFP-VOL; and investment TFP volatility shock, ΔI-TFP-VOL. The predictive projection is $\frac{1}{h}\sum_{j=1}^{h}\Delta y_{t+j} = \beta_0 + \beta_h'[\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t] + error$. The table reports the slope coefficients β_h, $t-$statistics, and the adjusted R^2s for the predictive horizons of $h = 1, 4, 8, 12$, and 20 quarters, for the corresponding aggregate growth series Δy. Standard errors are Newey-West adjusted. Data on sectoral TFP growth are from 1947Q2-2014Q2 and on sectoral volatilities from 1949Q1-2014Q2 (first W quarters used to construct realized variances). Data on consumption, GDP, and earnings growth are quarterly from 1947Q2-2014Q2. Data on sales are from 1962Q1-2014Q2.

Offset	$\beta_{\text{C-TFP}}$	$\beta_{\text{I-TFP}}$	$\beta_{\text{C-TFP-VOL}}$	$\beta_{\text{I-TFP-VOL}}$	$Adj-R^2$
Consumption growth:					
1Q Ahead	0.27 [3.29]	0.05 [0.62]	-0.04 [-3.78]	0.06 [4.68]	0.067
4Q Ahead	0.28 [3.35]	-0.14 [-2.10]	-0.02 [-2.72]	0.03 [2.49]	0.089
8Q Ahead	0.24 [3.30]	-0.14 [-2.48]	-0.02 [-2.59]	0.02 [2.44]	0.082
12Q Ahead	0.21 [2.79]	-0.14 [-2.72]	-0.02 [-2.23]	0.02 [2.06]	0.086
20Q Ahead	0.17 [1.77]	-0.11 [-1.64]	-0.01 [-1.71]	0.02 [1.67]	0.086
GDP growth:					
1Q Ahead	0.50 [4.05]	0.16 [1.49]	-0.09 [-4.09]	0.12 [4.45]	0.148
4Q Ahead	0.48 [2.88]	-0.21 [-1.62]	-0.04 [-2.21]	0.04 [2.06]	0.109
8Q Ahead	0.33 [2.58]	-0.21 [-1.97]	-0.02 [-1.98]	0.02 [1.78]	0.064
12Q Ahead	0.27 [2.32]	-0.18 [-2.17]	-0.02 [-1.99]	0.02 [1.74]	0.071
20Q Ahead	0.18 [1.53]	-0.14 [-1.62]	-0.01 [-1.36]	0.01 [1.22]	0.057
Sales growth:					
1Q Ahead	-0.45 [-0.46]	1.88 [2.57]	-0.13 [-0.47]	0.11 [0.36]	0.004
4Q Ahead	1.21 [2.76]	-0.21 [-0.59]	-0.14 [-3.29]	0.17 [3.32]	0.110
8Q Ahead	1.08 [2.94]	-0.39 [-1.70]	-0.10 [-2.94]	0.13 [2.89]	0.103
12Q Ahead	0.95 [2.37]	-0.37 [-1.43]	-0.09 [-2.23]	0.10 [2.28]	0.116
20Q Ahead	0.80 [1.97]	-0.44 [-1.66]	-0.06 [-1.67]	0.07 [1.64]	0.115
Net earnings growth:					
1Q Ahead	4.02 [1.67]	1.06 [0.85]	-0.58 [-1.93]	0.69 [2.28]	0.062
4Q Ahead	3.19 [1.56]	-0.62 [-0.40]	-0.26 [-1.59]	0.32 [1.66]	0.028
8Q Ahead	1.77 [1.24]	-1.00 [-0.84]	-0.10 [-0.93]	0.12 [0.89]	0.004
12Q Ahead	1.05 [1.01]	-0.74 [-0.71]	-0.06 [-0.71]	0.06 [0.67]	0.002
20Q Ahead	0.40 [1.14]	-0.26 [-0.69]	-0.02 [-0.78]	0.02 [0.71]	0.007

Table 3

Sectoral shocks and aggregate inputs growth

The table shows the evidence from the projection of future aggregate capital growth rate measures (Panel A) and labor growth rate measures (Panel B) on the current sectoral shocks: consumption TFP innovation, ΔC-TFP; investment TFP innovation, ΔI-TFP; consumption TFP volatility shock, ΔC-TFP-VOL; and investment TFP volatility shock, ΔI-TFP-VOL. The predictive projection is $\frac{1}{h}\sum_{j=1}^{h}\Delta y_{t+j} = \beta_0 + \beta_h'[\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t] + error$. The table reports the slope coefficients β_h, $t-$statistics, and the adjusted R^2s for the predictive horizons of $h = 1, 4, 8, 12$, and 20 quarters, for the corresponding aggregate growth series Δy. Standard errors are Newey-West adjusted. The sample for sectoral TFP volatilities is described in Table **1**. Data on all dependent variables, except Capex, are quarterly from 1947Q2-2014Q2. Quarterly capital expenditures data from Compustat are from 1985Q1-2014Q2.

Offset	$\beta_{\text{C-TFP}}$	$\beta_{\text{I-TFP}}$	$\beta_{\text{C-TFP-VOL}}$	$\beta_{\text{I-TFP-VOL}}$	$Adj-R^2$
Panel A: Aggregate growth of capital measures					
Capital investment growth:					
1Q Ahead	1.10 [3.53]	0.66 [2.50]	-0.15 [-3.21]	0.21 [4.09]	0.223
4Q Ahead	1.09 [2.41]	-0.28 [-0.85]	-0.09 [-1.93]	0.11 [1.93]	0.109
8Q Ahead	0.80 [1.83]	-0.43 [-1.29]	-0.07 [-1.75]	0.08 [1.68]	0.060
12Q Ahead	0.63 [1.61]	-0.41 [-1.37]	-0.05 [-1.45]	0.05 [1.33]	0.052
20Q Ahead	0.41 [1.46]	-0.36 [-1.48]	-0.03 [-1.25]	0.03 [1.10]	0.055
Capital expenditures growth:					
1Q Ahead	-3.93 [-1.24]	5.05 [1.96]	-1.15 [-2.00]	1.09 [1.52]	0.077
4Q Ahead	0.73 [0.56]	0.78 [0.77]	-0.20 [-1.88]	0.24 [1.84]	0.078
8Q Ahead	1.07 [1.08]	0.11 [0.14]	-0.17 [-2.50]	0.22 [2.67]	0.056
12Q Ahead	0.75 [1.29]	0.17 [0.25]	-0.10 [-2.59]	0.13 [2.80]	0.050
20Q Ahead	0.08 [0.15]	0.20 [0.35]	-0.03 [-0.54]	0.03 [0.63]	-0.012
Relative investment-price growth:					
1Q Ahead	0.61 [4.09]	-0.63 [-3.76]	-0.04 [-1.45]	0.04 [1.39]	0.059
4Q Ahead	0.37 [1.83]	-0.47 [-3.42]	-0.01 [-0.54]	0.01 [0.36]	0.078
8Q Ahead	0.36 [1.97]	-0.43 [-3.24]	-0.02 [-1.00]	0.01 [0.74]	0.111
12Q Ahead	0.34 [1.92]	-0.36 [-2.61]	-0.02 [-1.23]	0.02 [1.02]	0.105
20Q Ahead	0.38 [2.19]	-0.35 [-2.40]	-0.03 [-1.96]	0.03 [1.93]	0.149
Panel B: Aggregate growth of labor measures					
Hours growth:					
1Q Ahead	0.52 [3.86]	0.05 [0.39]	-0.07 [-4.12]	0.08 [4.45]	0.183
4Q Ahead	0.51 [2.65]	-0.25 [-1.71]	-0.04 [-2.11]	0.04 [1.99]	0.119
8Q Ahead	0.38 [2.40]	-0.27 [-2.04]	-0.03 [-2.08]	0.03 [1.88]	0.095
12Q Ahead	0.33 [2.28]	-0.25 [-2.29]	-0.02 [-2.05]	0.02 [1.85]	0.116
20Q Ahead	0.19 [1.76]	-0.19 [-2.03]	-0.01 [-1.40]	0.01 [1.12]	0.110
Wage growth:					
1Q Ahead	0.35 [2.90]	-0.10 [-0.91]	-0.05 [-2.62]	0.06 [2.69]	0.020
4Q Ahead	0.31 [3.37]	-0.23 [-2.71]	-0.03 [-2.65]	0.03 [2.69]	0.060
8Q Ahead	0.30 [3.73]	-0.23 [-3.19]	-0.02 [-2.58]	0.02 [2.49]	0.084
12Q Ahead	0.26 [2.67]	-0.21 [-2.64]	-0.02 [-2.00]	0.02 [1.92]	0.074
20Q Ahead	0.24 [1.93]	-0.16 [-1.58]	-0.02 [-1.92]	0.02 [2.03]	0.078

Table 4

Sectoral shocks and research & development

The table shows the results from the projection of future aggregate (Panel A) and sector-specific (Panel B) R&D related growth rates on the current sectoral shocks: consumption TFP innovation, ΔC-TFP; investment TFP innovation, ΔI-TFP; consumption TFP volatility shock, ΔC-TFP-VOL; and investment TFP volatility shock, ΔI-TFP-VOL. The predictive projection is $\frac{1}{h}\sum_{j=1}^{h}\Delta R\&D_{t+j} = \beta_0 + \beta_h'[\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t] + error$. The table reports the slope coefficients β_h, t−statistics, and the adjusted R^2s for the predictive horizons of $h = 1, 4, 8, 12,$ and 20 quarters. Standard errors are Newey-West adjusted. The sample for sectoral TFP volatilities is described in Table **1**. Aggregate R&D-related data are quarterly from 1947Q2-2014Q2 and obtained from BEA. Sectoral R&D data, for R&D intensive industries, are annual from 1986 - 2007.

Offset	$\beta_{\text{C-TFP}}$	$\beta_{\text{I-TFP}}$	$\beta_{\text{C-TFP-VOL}}$	$\beta_{\text{I-TFP-VOL}}$	$Adj-R^2$
Panel A: Aggregate R&D activity					
Growth of the contribution of research and development to GDP:					
1Q Ahead	1.19 [3.56]	-0.72 [-1.99]	-0.12 [-3.68]	0.14 [3.83]	0.11
4Q Ahead	1.32 [4.20]	-0.86 [-3.39]	-0.11 [-4.37]	0.13 [4.19]	0.18
8Q Ahead	1.12 [4.60]	-0.76 [-3.80]	-0.09 [-4.00]	0.10 [3.94]	0.16
12Q Ahead	1.05 [4.17]	-0.76 [-3.80]	-0.08 [-3.88]	0.09 [3.76]	0.16
20Q Ahead	1.03 [3.40]	-0.80 [-3.37]	-0.08 [-3.19]	0.08 [3.12]	0.20
Nonresidential research and development investment growth:					
1Q Ahead	1.05 [2.51]	-0.45 [-1.07]	-0.12 [-2.68]	0.15 [2.92]	0.05
4Q Ahead	1.35 [3.69]	-0.82 [-2.47]	-0.13 [-3.75]	0.15 [3.89]	0.14
8Q Ahead	1.20 [3.55]	-0.82 [-2.77]	-0.10 [-3.41]	0.11 [3.52]	0.18
12Q Ahead	1.22 [3.29]	-0.87 [-3.13]	-0.09 [-3.61]	0.10 [3.59]	0.23
20Q Ahead	1.08 [3.58]	-0.85 [-3.45]	-0.08 [-3.68]	0.09 [3.65]	0.29
Research and development as fraction of real private fixed investment:					
1Q Ahead	17.75 [2.18]	-6.41 [-0.86]	-2.63 [-3.11]	3.16 [3.33]	0.04
4Q Ahead	20.38 [2.88]	-11.11 [-1.82]	-1.84 [-3.34]	2.13 [3.27]	0.09
8Q Ahead	15.78 [2.96]	-11.36 [-2.21]	-1.34 [-2.96]	1.43 [2.69]	0.08
12Q Ahead	17.07 [3.53]	-12.04 [-3.00]	-1.33 [-3.62]	1.47 [3.31]	0.14
20Q Ahead	15.57 [4.12]	-13.15 [-4.43]	-1.15 [-3.73]	1.21 [3.41]	0.22
Panel B: R&D investment of R&D-intensive sectors					
Scientific R&D investment growth:					
1Y Ahead	57.61 [2.69]	-40.98 [-2.42]	-6.11 [-3.23]	8.08 [3.39]	0.23
2Y Ahead	57.80 [3.08]	-37.02 [-2.60]	-5.91 [-3.87]	7.88 [3.96]	0.26
4Y Ahead	42.43 [4.71]	-27.50 [-3.46]	-4.57 [-3.20]	5.62 [3.66]	0.09
Chemical R&D investment growth:					
1Y Ahead	12.30 [1.45]	-4.20 [-0.90]	-3.24 [-2.02]	3.88 [1.90]	0.02
2Y Ahead	9.28 [1.38]	-2.03 [-0.47]	-1.88 [-2.50]	2.32 [2.44]	0.03
4Y Ahead	11.87 [3.80]	-6.20 [-2.51]	-1.95 [-3.26]	2.11 [3.44]	0.39
Software R&D investment growth:					
1Y Ahead	-12.45 [-0.64]	13.64 [1.05]	-1.39 [-0.52]	1.43 [0.44]	0.03
2Y Ahead	0.93 [0.07]	2.35 [0.29]	-2.27 [-1.31]	2.14 [1.99]	0.27
4Y Ahead	21.72 [1.85]	-14.12 [-1.78]	-3.38 [-2.51]	3.40 [2.08]	0.47
Communication R&D investment growth:					
1Y Ahead	2.10 [0.10]	25.03 [1.91]	-3.20 [-0.77]	3.89 [0.71]	0.01
2Y Ahead	20.60 [0.83]	9.44 [0.73]	-4.54 [-1.61]	5.67 [1.48]	0.05
4Y Ahead	50.85 [2.60]	-19.52 [-1.32]	-8.62 [-3.13]	9.94 [3.01]	0.33

Table 5

Sectoral shocks and detrended macroeconomic variables

The table shows the results from the projection of contemporaneous and future business cycle component of selected macroeconomic variables, averaged over h periods, on the current sectoral shocks: consumption TFP innovation, ΔC-TFP; investment TFP innovation, ΔI-TFP; consumption TFP volatility shock, ΔC-TFP-VOL; and investment TFP volatility shock, ΔI-TFP-VOL. The predictive projection ($h > 1$) is $\frac{1}{h}\sum_{j=1}^{h} y_{t+j}^{\text{cycle}} = \beta_0 + \beta_h'[\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t] + error$. The contemporaneous projection ($h = 0$) is the same, but the dependent variable is $\Delta y_t^{\text{cycle}}$. The cyclical component y^{cycle} of a variable y is obtained from one-sided HP filtering the trending level-series of y with a smoothing parameter of 1600. The table reports the slope coefficients β_h, $t-$statistics, and the adjusted R^2s for the contemporaneous projection ($h = 0$), and the predictive horizons of $h = 1, 4, 8, 12$, and 20 quarters, for the corresponding business cycle variable y^{cycle}. Standard errors are Newey-West adjusted. The sample for sectoral TFP volatilities is described in Table **1**. The data on detrended consumption, GDP, investment, and hours are quarterly from 1947Q2-2014Q2.

Offset	$\beta_{\text{C-TFP}}$	$\beta_{\text{I-TFP}}$	$\beta_{\text{C-TFP-VOL}}$	$\beta_{\text{I-TFP-VOL}}$	$Adj-R^2$
Detrended consumption:					
0Q Ahead	0.21 [0.33]	1.33 [2.05]	-0.08 [-1.19]	0.14 [1.62]	0.060
1Q Ahead	0.51 [0.70]	1.39 [2.15]	-0.16 [-2.22]	0.22 [1.47]	0.098
4Q Ahead	1.09 [1.26]	0.59 [0.94]	-0.17 [-1.97]	0.21 [1.98]	0.093
8Q Ahead	1.26 [1.31]	0.03 [0.05]	-0.15 [-1.76]	0.19 [1.74]	0.063
12Q Ahead	1.08 [1.13]	-0.25 [-0.37]	-0.11 [-1.39]	0.13 [1.34]	0.034
20Q Ahead	0.53 [0.62]	-0.42 [-0.63]	-0.04 [-0.67]	0.04 [0.56]	-0.001
Detrended GDP:					
0Q Ahead	0.79 [1.38]	1.41 [2.20]	-0.14 [-2.55]	0.22 [3.27]	0.160
1Q Ahead	1.14 [2.03]	1.38 [2.51]	-0.23 [-3.52]	0.32 [4.06]	0.214
4Q Ahead	1.56 [2.30]	0.54 [1.10]	-0.20 [-2.81]	0.26 [2.94]	0.177
8Q Ahead	1.29 [1.73]	-0.09 [-0.16]	-0.13 [-1.95]	0.16 [1.89]	0.077
12Q Ahead	0.98 [1.41]	-0.27 [-0.53]	-0.09 [-1.52]	0.10 [1.44]	0.038
20Q Ahead	0.22 [0.43]	-0.25 [-0.63]	-0.01 [-0.28]	0.00 [0.11]	-0.009
Detrended capital investment:					
0Q Ahead	0.33 [0.13]	4.12 [1.80]	-0.29 [-1.35]	0.48 [1.89]	0.063
1Q Ahead	1.92 [0.77]	4.03 [1.84]	-0.53 [-2.26]	0.76 [2.70]	0.111
4Q Ahead	4.21 [1.54]	1.65 [0.82]	-0.62 [-2.35]	0.80 [2.55]	0.113
8Q Ahead	4.95 [1.71]	-0.81 [-0.39]	-0.57 [-2.29]	0.68 [2.31]	0.077
12Q Ahead	4.37 [1.64]	-1.89 [-0.95]	-0.41 [-1.88]	0.47 [1.84]	0.051
20Q Ahead	2.04 [1.37]	-2.17 [-1.54]	-0.10 [-1.03]	0.08 [0.78]	0.036
Detrended hours:					
0Q Ahead	-0.01 [-0.01]	1.04 [1.36]	-0.09 [-1.37]	0.13 [1.82]	0.044
1Q Ahead	0.61 [0.78]	0.86 [1.16]	-0.16 [-2.36]	0.21 [2.79]	0.083
4Q Ahead	1.31 [1.68]	0.15 [0.24]	-0.18 [-2.47]	0.22 [2.62]	0.092
8Q Ahead	1.43 [1.85]	-0.41 [-0.66]	-0.15 [-2.30]	0.18 [2.31]	0.068
12Q Ahead	1.29 [1.82]	-0.62 [-1.05]	-0.12 [-1.99]	0.13 [1.99]	0.055
20Q Ahead	0.52 [1.20]	-0.55 [-1.25]	-0.02 [-0.84]	0.02 [0.65]	0.024

Table 6

Sectoral shocks and markups

The table shows the results from the projection of future aggregate (Panel A) and sectoral (Panel B) markups, averaged over h periods, on the current sectoral shocks: consumption TFP innovation, ΔC-TFP; investment TFP innovation, ΔI-TFP; consumption TFP volatility shock, ΔC-TFP-VOL; and investment TFP volatility shock, ΔI-TFP-VOL. The predictive projection is $\frac{1}{h}\sum_{j=1}^{h} \text{markup}_{t+j} = \beta_0 + \beta_h'[\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t] + error$. The table reports the slope coefficients β_h, $t-$statistics, and the adjusted R^2s for the predictive horizons of $h = 1, 4, 8, 12$, and 20 quarters. Standard errors are Newey-West adjusted. Markups based on labor share are defined as Eq. (2.4) in Rotemberg and Woodford (1999), $markup = s_H^{-1}$, where s_H is business sector labor share. Markups adjusted for non-Cobb-Douglas production are defined as Eq. (2.7) in Rotemberg and Woodford (1999), $markup = a\hat{y} - \hat{s}_H$, where $y = log(Y/K)$, Y is gross value added of nonfinancial corporate business, K is nonfinancial corporate business nonfinancial assets, and a is a log-lineraization parameter that relates to the elasticity of substitution between capital and labor inputs and equals to four (see Rotemberg and Woodford, 1999, p.15). Markups adjusted for labor adjustment costs are based on Eq. (2.15) from Rotemberg and Woodford (1999), $markup = a\hat{y} - \hat{s}_H - \hat{\Omega}$, and $\hat{\Omega} = c[\hat{\gamma}_{H_t} - \beta E_t\hat{\gamma}_{H_{t+1}}]$, where γ_{H_t} is average weekly hours growth. $E_t\hat{\gamma}_{H_{t+1}}$ is obtained by the fitted value of a regression of $\hat{H}_{t+1}$ (future hours growth) on two lags of $\hat{H}_t$, on the growth rate of gross value added, and on consumption expenditures to GDP. Following Rotemberg and Woodford (1999), the parameter β is equal to 0.99, and c is equal to 4. The sample for sectoral TFP volatilities is described in Table **1**. Aggregate markup data (Panel A) are quarterly, from 1947Q2-2014Q2. Sectoral markup data (Panel B) are from annual from 1987-2014 and are adjusted for labor adjustment costs.

Offset	$\beta_{\text{C-TFP}}$	$\beta_{\text{I-TFP}}$	$\beta_{\text{C-TFP-VOL}}$	$\beta_{\text{I-TFP-VOL}}$	$Adj-R^2$
Panel A: Aggregate business sector markups					
Markups based on labor share:					
1Q Ahead	-2.39 [-2.90]	2.53 [3.65]	0.12 [1.83]	-0.11 [-1.51]	0.11
4Q Ahead	-2.44 [-2.94]	2.38 [3.31]	0.16 [2.49]	-0.17 [-2.37]	0.11
8Q Ahead	-2.65 [-3.39]	2.31 [3.31]	0.18 [2.98]	-0.20 [-2.92]	0.12
12Q Ahead	-2.84 [-3.26]	2.36 [3.10]	0.20 [3.03]	-0.22 [-3.02]	0.15
20Q Ahead	-3.28 [-2.97]	2.51 [2.88]	0.26 [2.71]	-0.29 [-2.64]	0.25
Markups adjusted for non-Cobb-Douglas production function:					
1Q Ahead	-1.27 [-0.91]	-0.05 [-0.05]	0.11 [0.99]	-0.16 [-1.24]	0.01
4Q Ahead	-1.77 [-1.29]	0.29 [0.25]	0.19 [1.73]	-0.25 [-2.01]	0.03
8Q Ahead	-2.16 [-1.63]	0.73 [0.62]	0.20 [1.86]	-0.25 [-2.12]	0.03
12Q Ahead	-2.34 [-1.60]	1.01 [0.77]	0.20 [1.85]	-0.26 [-2.08]	0.04
20Q Ahead	-2.86 [-1.66]	1.51 [1.03]	0.26 [1.87]	-0.31 [-1.96]	0.07
Markups adjusted for labor adjustment costs:					
1Q Ahead	-2.10 [-1.43]	-1.13 [-0.81]	0.34 [1.98]	-0.40 [-2.01]	0.06
4Q Ahead	-2.60 [-1.67]	0.57 [0.46]	0.29 [2.05]	-0.35 [-2.15]	0.05
8Q Ahead	-2.75 [-1.78]	0.89 [0.69]	0.25 [1.96]	-0.31 [-2.11]	0.05
12Q Ahead	-2.94 [-1.75]	1.30 [0.90]	0.26 [1.95]	-0.32 [-2.06]	0.05
20Q Ahead	-3.21 [-1.62]	1.76 [1.07]	0.29 [1.80]	-0.34 [-1.84]	0.06
Panel B: Sectoral markups					
Nondurable markups:					
1Y Ahead	-3.01 [-0.59]	2.02 [0.50]	2.26 [1.61]	-2.71 [-1.66]	0.10
2Y Ahead	-5.36 [-1.21]	3.64 [0.89]	1.67 [1.35]	-2.07 [-1.40]	0.11
4Y Ahead	-6.29 [-1.50]	5.32 [1.38]	2.16 [1.37]	-2.40 [-1.21]	0.01
Durable markups:					
1Y Ahead	-1.59 [-0.71]	1.04 [0.71]	1.17 [1.92]	-1.46 [-2.07]	0.02
2Y Ahead	-1.12 [-0.63]	1.12 [0.78]	0.77 [1.73]	-0.97 [-1.85]	0.07
4Y Ahead	-0.79 [-0.50]	1.16 [0.87]	0.67 [1.45]	-0.74 [-1.29]	0.06

Table 7

Sectoral shocks and the cross-section of returns

The table shows the estimates of the market prices of risks (Panel A) and the exposures (Panel B) to consumption TFP, C-TFP; investment TFP, I-TFP; consumption TFP volatility, C-TFP-VOL; and investment TFP volatility, I-TFP-VOL, risks for the cross-section of equity returns. The cross-section includes the market, ten portfolios sorted on book to market (bm), ten portfolios sorted on momentum (mom), and ten portfolios sorted on size (size). The reported market prices of risks are divided by 100. *T*-statistics are in brackets and are based on Newey-West standard errors from GMM estimation. The sample for sectoral TFP volatilities is described in Table **1**. The return data are quarterly from 1947Q2-2014Q2.

Panel A: Market prices of risk (Λ)

	$\lambda_{\text{C-TFP}}$	$\lambda_{\text{I-TFP}}$	$\lambda_{\text{C-TFP-VOL}}$	$\lambda_{\text{I-TFP-VOL}}$
λ	2.39	1.36	-0.43	0.70
	[2.30]	[1.37]	[-3.49]	[4.75]

Panel B: Exposures to risks (β)

	$\beta_{\text{C-TFP}}$	$\beta_{\text{I-TFP}}$	$\beta_{\text{C-TFP-VOL}}$	$\beta_{\text{I-TFP-VOL}}$
Market	2.80	-0.94	-0.06	0.08
bm1	3.04	-0.78	-0.01	0.03
bm2	2.48	-1.06	-0.04	0.04
bm3	2.35	-1.23	-0.04	0.05
bm4	2.43	-0.85	-0.13	0.16
bm5	2.60	-1.17	-0.04	0.03
bm6	2.88	-0.90	-0.13	0.16
bm7	2.42	-0.75	-0.07	0.09
bm8	3.27	-0.58	-0.19	0.25
bm9	2.76	-0.53	-0.07	0.10
bm10	3.13	0.08	-0.07	0.09
mom1	5.41	-2.44	-0.06	0.04
mom2	4.07	-1.58	0.01	-0.01
mom3	3.19	-1.39	-0.12	0.12
mom4	2.73	-0.77	-0.03	0.05
mom5	2.78	-0.97	-0.11	0.16
mom6	2.51	-0.95	-0.09	0.11
mom7	2.25	-0.94	-0.14	0.18
mom8	2.43	-0.83	-0.07	0.09
mom9	2.71	-0.76	-0.07	0.11
mom10	3.15	-0.64	-0.04	0.16
size1	3.58	-0.31	0.08	-0.07
size2	3.37	-0.83	0.08	-0.08
size3	3.05	-0.70	0.07	-0.06
size4	3.39	-1.06	0.01	0.00
size5	3.06	-1.01	0.05	-0.06
size6	2.96	-1.10	0.01	0.00
size7	2.87	-0.97	-0.04	0.04
size8	2.52	-0.85	-0.01	0.02
size9	2.42	-0.75	-0.08	0.09
size10	2.78	-0.90	-0.08	0.11

Table 8

Summary of pricing statistics from a four-factor model

The table shows summary asset-pricing results of a four-factor model: consumption TFP, C-TFP; investment TFP, I-TFP; consumption TFP volatility, C-TFP-VOL; and investment TFP volatility, I-TFP-VOL, risk factors. Panel A reports the adjusted R^2 of the second-stage regression (mean-excess returns projected on constant and risk exposures) from a Fama-Macbeth procedure, using a cross-section of ten book-to-market sorted portfolios, ten momentum sorted portfolios, ten size sorted portfolios, and the market portfolio. Panel B reports data and model counterpart quarterly spreads of quantile sorted portfolios, along the momentum dimension (MOM), book to market dimension (BM), size dimension (SIZE), Tobin's Q dimension (Q), operating profitability dimension (OP), and residual (idiosyncratic) variance of return (RVAR) dimension. Tobin's Q is measured as market-to-book ratio as in Hennessy, Levy, and Whited (2007). Operating profitability is measured via operating profits divided by book equity. Residual variance refers to the variance of the residuals from the Fama-French three-factor model using 60 days of lagged returns. Each spread is computed as the return of portfolio 1 (the portfolio of stocks with the lowest characteristic) minus the return of portfolios 5 (the portfolio of stocks with the highest characteristic). Panels B also shows the decomposition of the model-implied spreads ($Spread$) into the compensations for the four risk factors. The contribution of a risk factor to a model-implied spread includes the risk premium spread from the factor's own quantity of risk, as well as one-half of the risk premium spread coming from the covariance terms between the risk factor and other shocks in the model. The sample for sectoral TFP volatilities is described in Table **1**. The data for OP and RVAR sorted portfolios are from 1964Q1-2014Q2. All other return data are quarterly from 1947Q2-2014Q2.

Panel A: Adjusted R^2 of Fama-Macbeth second-stage projection						
Adj-R^2		0.69				
Panel B: Cross-sectional spreads						
Spread	Data	Model	$Spread_{\text{C-TFP}}$	$Spread_{\text{I-TFP}}$	$Spread_{\text{C-TFP-VOL}}$	$Spread_{\text{I-TFP-VOL}}$
MOM	-2.65	-0.83	1.15	-0.95	1.39	-2.43
BM	-1.00	-0.69	-0.08	-0.32	1.31	-1.60
SIZE	0.46	0.27	0.50	0.22	5.25	-5.70
Q	0.98	1.28	0.12	0.35	-0.70	1.52
OP	-0.79	-1.03	0.27	-0.20	-0.20	-0.90
RVAR	1.55	0.88	-2.84	1.18	-8.18	10.72

Table 9

Summary of pricing statistics from a two-factor model

The table shows summary asset pricing results of a two-factor model: consumption TFP, C-TFP, and investment TFP, I-TFP. Panel A reports the adjusted R^2 of the second-stage regression (mean-excess returns projected on constant and risk exposures) from a Fama-Macbeth procedure, using the same cross-section as in Panel A of Table **8**. Panel B reports data and model counterpart of quarterly spreads, based on quantile sorted portfolios, along the same dimensions and sample as in Panel B of Table **8**.

Panel A: Adjusted R^2 of Fama-Macbeth second-stage projection				
Adj-R^2		0.49		
Panel B: Cross-sectional spreads				
Spread	Data	Model	$Spread_{\text{C-TFP}}$	$Spread_{\text{I-TFP}}$
MOM	-2.65	0.50	1.87	-1.37
BM	-1.00	-0.55	0.05	-0.59
SIZE	0.46	1.29	1.36	-0.07
Q	0.98	0.41	0.07	0.34
OP	-0.79	0.51	0.43	0.08
RVOL	1.55	-3.12	-5.26	2.14

Table 10

Sectoral volatility feedback to future technological growth

The table shows the volatility feedback evidence from projections of one-quarter-ahead sectoral TFP growth rates, on the current sectoral shocks: consumption TFP innovation, ΔC-TFP; investment TFP innovation, ΔI-TFP; consumption TFP volatility shock, ΔC-TFP-VOL; and investment TFP volatility shock, ΔI-TFP-VOL: $\Delta j - TFP_{t+1} = \beta_0 + \beta_h'[\Delta\text{C-TFP}_t, \Delta\text{I-TFP}_t, \Delta\text{C-TFP-VOL}_t, \Delta\text{I-TFP-VOL}_t] + error, \quad j \in \{C, I\}$. Shocks are normalized by their respective standard deviations. The table reports the slope coefficients β_h, $t-$statistics, and the adjusted R^2s. Standard errors are Newey-West adjusted. The data on first-moment sectoral shocks are quarterly from 1947Q2-2014Q2 and on sectoral volatilities from 1949Q1-2014Q2.

$\beta_{\text{C-TFP}}$	$\beta_{\text{I-TFP}}$	$\beta_{\text{C-TFP-VOL}}$	$\beta_{\text{I-TFP-VOL}}$	$Adj - R^2$
1Q Ahead C-TFP:				
0.46 [3.69]	-0.23 [-1.97]	-0.78 [-2.06]	0.82 [2.20]	0.047
1Q Ahead I-TFP:				
-0.10 [-0.67]	0.38 [3.32]	-0.32 [-0.67]	0.42 [0.88]	0.056

Table 11

Model-implied macroeconomic and pricing moments against data counterparts

The table presents model-implied mean, standard deviation, and autocorrelation for key macroeconomic growth rates and aggregate pricing variables against their empirical counterparts. Panel A shows the results for the macroeconomic growth (in log-real rates) of consumption growth ΔC, output growth ΔY, investment expenditures growth ΔI, and relative price of investment growth ΔP_I. Panel B shows the results for the real market excess return, R_m^e, and the real risk-free rate, R_f. In the model, the market excess return is levered up using a factor of $5/3$. The model-implied macroeconomic moments are computed from simulated data. I simulate the model at a quarterly frequency and then time aggregate the data to annual observations. I report median moments along with the 5% and 95% percentiles, across 10,000 simulations, each with a length of 268 quarters, similar to the length of the data time series. The data moments are computed using annual data from 1947-2014.

	Model (Annualized)			Data (1947-2014)		
	Mean	Std.dev.	Ac(1)	Mean	Std.dev.	Ac(1)
Panel A: Macroeconomic growth moments						
ΔC	1.92 [0.99,2.84]	2.17 [1.70,2.67]	0.54 [0.33,0.70]	1.92	1.52	0.49
ΔY	1.93 [0.98,2.81]	2.21 [1.67,2.71]	0.53 [0.28,0.69]	1.98	2.28	0.18
ΔI	1.88 [0.89,2.99]	6.64 [5.54,7.90]	0.30 [0.10,0.48]	1.67	6.75	0.18
ΔP_I	-0.95 [-2.08,0.24]	3.48 [2.89,4.08]	0.30 [0.07,0.47]	-0.97	3.62	0.45
Panel B: Pricing moments						
R_m^e	6.64 [6.16,7.20]	8.01 [7.06,9.03]	-0.00 [-0.19,0.14]	6.20	17.63	-0.03
R_f	1.37 [0.75,2.02]	1.27 [1.02,1.69]	0.79 [0.69,0.87]	0.89	1.72	0.73

Table 12

Model-implied market prices of risk and risk exposures

The table presents model-implied market prices of risk (λ) and risk exposures (β) to consumption TFP innovation risk (C-TFP shock $\varepsilon_{c,t}$), investment TFP innovation risk (I-TFP shock $\varepsilon_{i,t}$), consumption TFP volatility risk (C-TFP-VOL shock $\varepsilon_{\sigma,c,t}$), and investment TFP volatility risk (I-TFP-VOL shock $\varepsilon_{\sigma,i,t}$). The exposures (betas) to the risk factors are reported for consumption firms (V_c), investment firms (V_i), and the market ($V_m = V_c + V_i$). Panel A reports model implied market prices and betas for the benchmark model. Panel B shows the results for a model with no volatility feedback ($\tau = 0$) and no monopolistic competition. The reported market prices of risks are divided by 100. The construction of market prices of risk and betas is described in Section 5.3.

	C-TFP	I-TFP	C-TFP-VOL	I-TFP-VOL
Panel A: Benchmark				
Market prices of risk	0.25	0.10	-59.89	55.05
Market betas	0.59	-0.02	-123.77	57.65
Consumption betas	0.60	-0.06	-122.38	55.14
Investment betas	0.59	-0.01	-128.24	66.30
Panel B: Simplified model (perfect competition)				
Market prices of risk	0.25	0.10	-58.29	-11.48
Market betas	1.00	-0.64	-50.60	86.91
Consumption betas	1.00	-0.70	-43.48	78.81
Investment betas	1.00	-0.52	-66.99	105.56

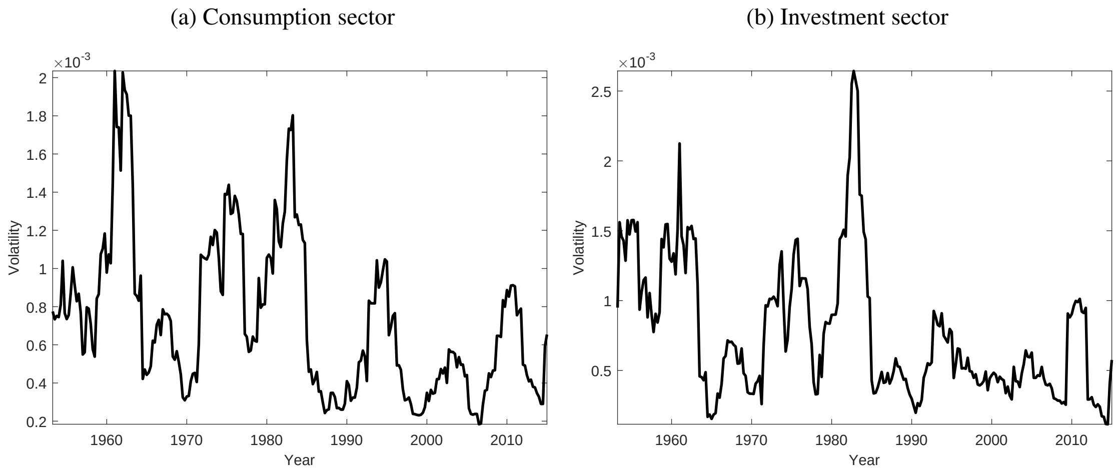


Fig. 1. Sectoral realized volatilities over time. The figure shows time series plots of the sectoral TFP realized variations. Panel (a) (Panel (b)) plots the variation of the consumption (investment) sector's productivity.

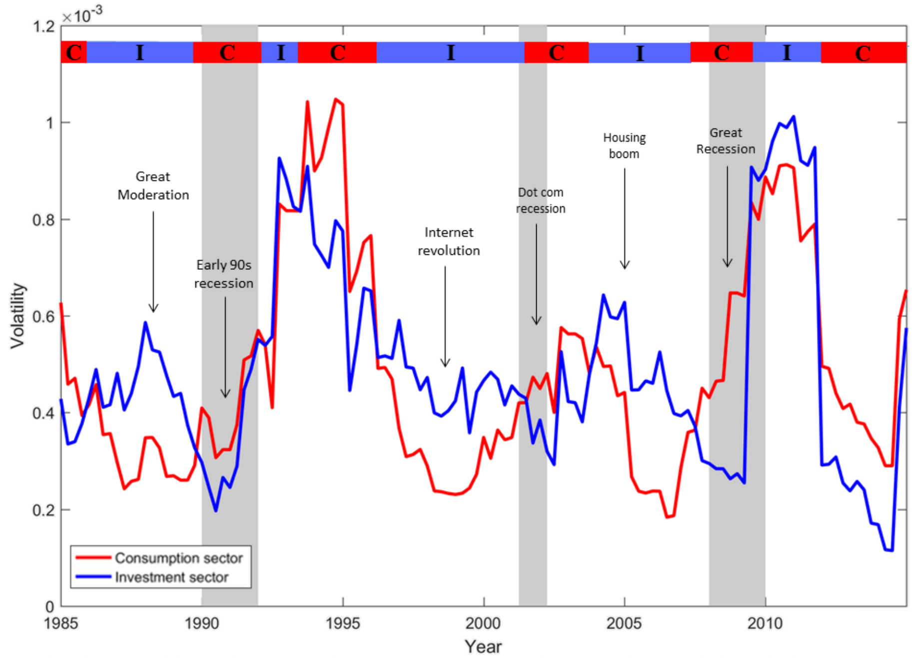
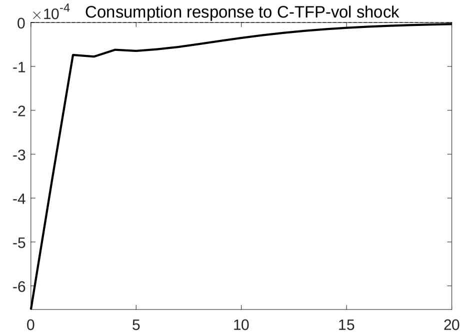
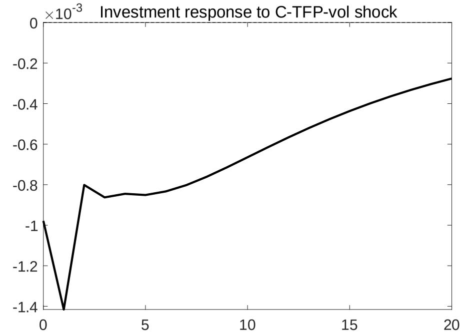


Fig. 2. Post-Great moderation volatility regimes. The figure shows the sectoral TFP realized variations during the Great Moderation era, for the consumption sector (red), and the investment sector (blue). The bar over the figure marks in red regimes in which the TFP variation of the consumption sector dominates that of the investment sector. The bar shows in blue regimes in which the investment sector's TFP variation dominates the that of the consumption sector. Shaded regions represent NBER recessions.

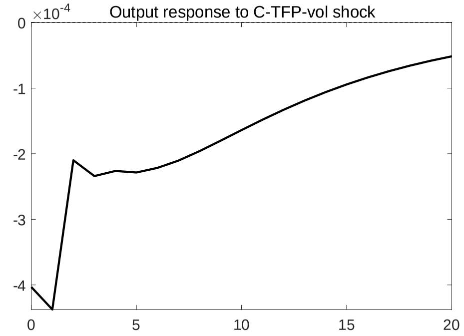
(a) Consumption response to consumption TFP volatility shock



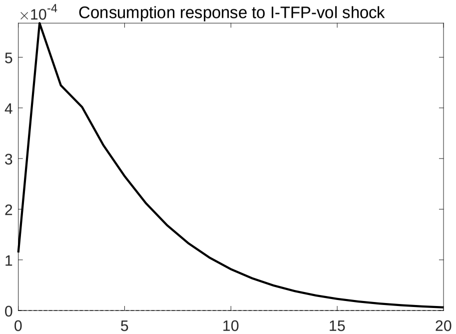
(b) Capital investment response to consumption TFP volatility shock



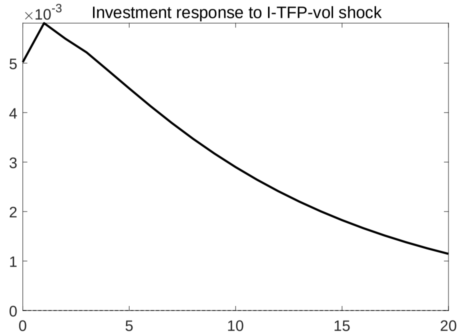
(c) Output response to consumption TFP volatility shock



(d) Consumption response to investment TFP volatility shock



(e) Capital investment response to investment TFP volatility shock



(f) Output response to investment TFP volatility shock

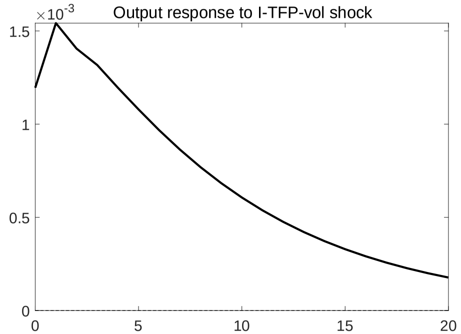
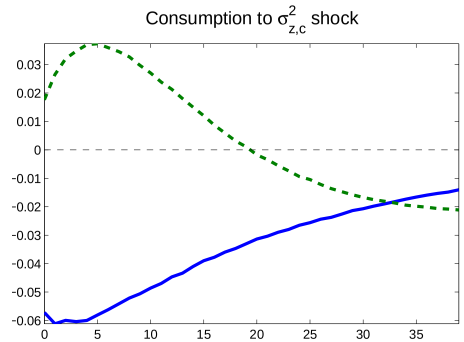
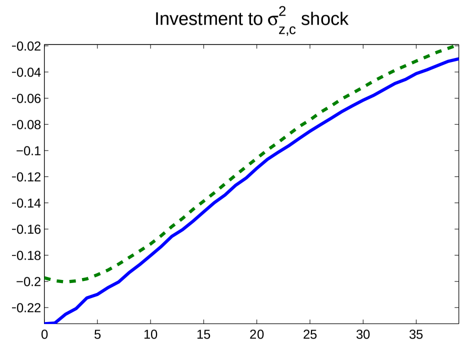


Fig. 3. Data impulse response of detrended consumption, output, and investment to sectoral volatilities. The figure shows impulse responses of the cyclical component of consumption, private sector output, and capital investment to one standard deviation shocks of consumption TFP volatility (C-TFP-vol) and investment TFP volatility (I-TFP-vol). The impulse responses are computed from a VAR(1) that includes sectoral first-moment innovations, sectoral volatility shocks, and the economic variable of interest. The cyclical component of each macroeconomic variable is obtained using a one-sided HP filter. The horizontal axis represents quarters. The sample for sectoral TFP volatilities is described in Table **1**. Detrended consumption, investment, and output data are quarterly from 1947Q2-2014Q2.

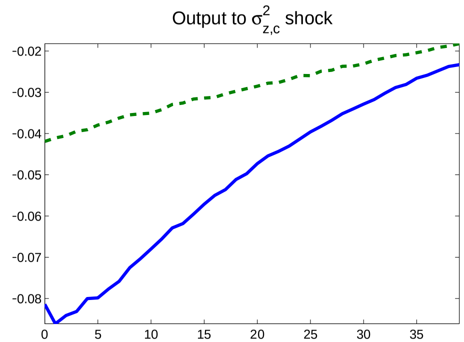
(a) Consumption response to consumption TFP volatility shock



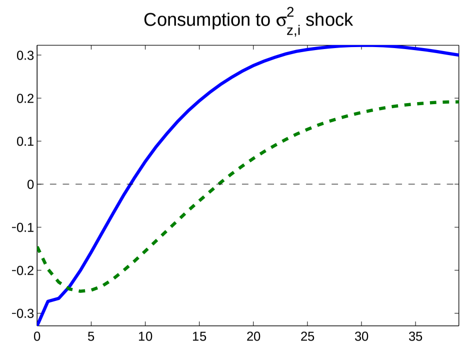
(b) Investment response to consumption TFP volatility shock



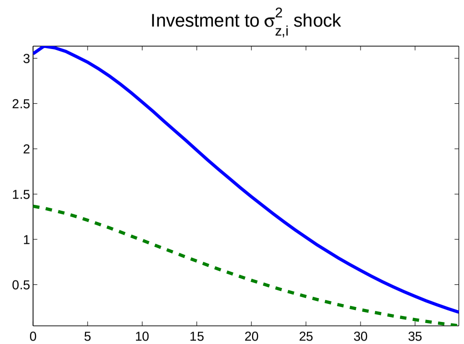
(c) Output response to consumption TFP volatility shock



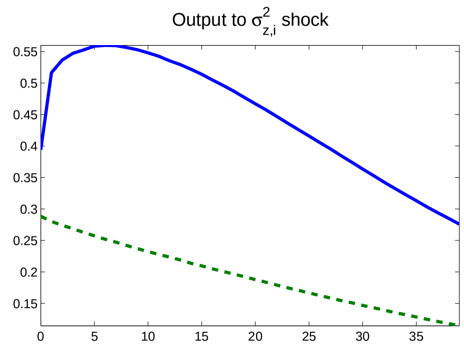
(d) Consumption response to investment TFP volatility shock



(e) Investment response to investment TFP volatility shock



(f) Output response to investment TFP volatility shock



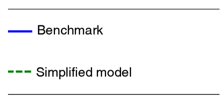
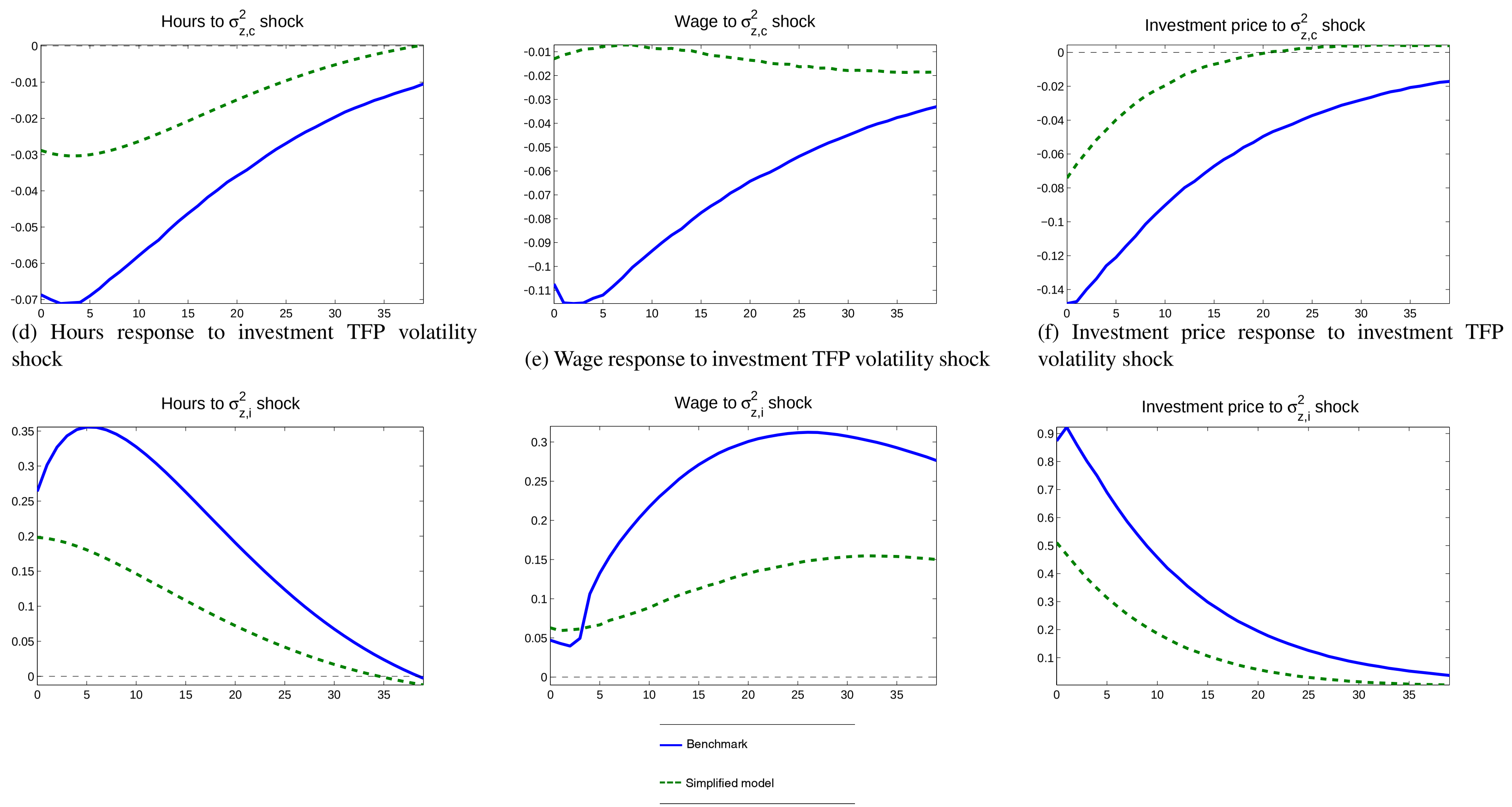


Fig. 4. Model impulse response of detrended consumption, output, and investment to sectoral volatilities. The figure shows impulse responses of model-detrended real consumption, investment expenditures, and output to one standard deviation shocks of consumption TFP volatility (σ^2_{zc}) and investment TFP volatility (σ^2_{zi}). The impulse responses are computed using simulated model data. The solid blue line shows impulse responses from the benchmark model. The dashed green line shows impulse responses from a "simplified model" with an identical calibration as the benchmark model but with perfect competition ($\mu_j \to \infty \quad j \in \{c, i\}$) and without a feedback from investment TFP volatility to future consumption TFP growth ($\tau = 0$). The horizontal axis represents quarters. The vertical axis represents percent deviations from the steady state.



(a) Hours response to consumption TFP volatility shock

(b) Wage response to consumption TFP volatility shock

(c) Investment price response to consumption TFP volatility shock

(d) Hours response to investment TFP volatility shock

(e) Wage response to investment TFP volatility shock

(f) Investment price response to investment TFP volatility shock

Fig. 5. Model impulse response of hours, detrended Wages and investment price to sectoral volatilities. The figure shows impulse responses of model-implied hours, detrended real wages, and real relative price of investment to one standard deviation shocks of consumption TFP volatility (σ^2_{zc}) and investment TFP volatility (σ^2_{zi}). The impulse responses are computed using simulated model data. The solid blue line shows impulse responses from the benchmark model. The dashed green line shows impulse responses from a "simplified model" with an identical calibration as the benchmark model but with perfect competition ($\mu_j \to \infty \quad j \in \{c, i\}$) and without a feedback from investment TFP volatility to future consumption TFP growth ($\tau = 0$). The horizontal axis represents quarters. The vertical axis represents percent deviations from the steady state.