Focusing on U.S. data, we show the existence of a significant positive link between uncertainty and reallocation from private firms that are intensive in R&D to government capital. This link is important because an increase in the aggregate share of government capital forecasts lower medium-term growth. We rationalize these novel empirical findings in a multi-sector production economy in which (i) growth is endogenously supported by risky R&D investments, (ii) the government accumulates capital that, at the equilibrium, is safe; and (iii) the representative agent has an explicit fear toward uncertainty.

This draft: August 28, 2017.
Key Words: Uncertainty shocks, Reallocation, Government Capital.
JEL classification: E3; E6; G18.
1 Introduction

It is well documented that periods of high uncertainty are often associated with sizable and prolonged economic slow downs during which both private consumption and aggregate investment decline. Less is known, however, on the impact of uncertainty shocks on the composition of national investments. In this manuscript, we study the reallocation motives that uncertainty shocks generate across different investment opportunities and we connect them to growth.

Specifically, focusing on US data, we look at different forms of private and government investments and document that when uncertainty increases, investment is reallocated toward forms of capital that provide safer returns. According to the data, the reallocation effect penalizes investments in R&D-intensive firms, that is, investments that are important to sustain long-term growth.

Furthermore, we show the existence of a significant positive link between uncertainty and reallocation from private to government capital. Government infrastructure represents a very sizeable 20% share of total US capital and is essential to correctly reconcile aggregate saving and investment flows. Our empirical tests suggest that this reallocation is a leading indicator of sluggish growth.

We rationalize these novel empirical findings in a multi-sector production economy with endogenous growth sustained by R&D investments that create new patents, a form of intangible capital. Like in Comin and Gertler (2006), patents grant monopolistic rents that are procyclical, volatile, and more sensitive to fundamental shocks than the marginal return of physical private capital and government capital. As a result, in our economy intangible capital is essential for growth, but it is also risky.

In contrast to Comin and Gertler (2006), the final consumption bundle is an isoe- lastic aggregator of a private good and a government-supplied good. Like the private
producers, the government needs labor and infrastructure capital for production. The main difference between the private final-good sector and the government is that the government offers its own good in a competitive manner, that is, charging just its marginal cost, whereas the private sector has monopoly power on the supply of private goods.

Under this assumption, the value of private capital depends on both the present value of its marginal productivity and the present value of future monopoly rents (Hayashi 1982). With recursive preferences, the latter component is extremely sensitive to uncertainty shocks, implying that even small increases in uncertainty can depress the market value of private capital. Under our benchmark calibration, the marginal product of capital is quite smooth and tangible capital is less risky than intangible capital, that is, the stock of patents in the economy. On the other hand, tangible capital is riskier than government capital because the value of the latter is not affected by monopolistic rents.

This setting explains the reallocation motives in our model: when uncertainty increases, the monopoly rent channel induces the representative agent to reduce drastically private R&D investment and cut down tangible capital. Simultaneously, more resources are allocated toward government capital. At the equilibrium, government capital offers a strong hedge against volatility shocks and is as safe as a risk-free bond. This reallocation, although efficient, comes at the cost of dimming future growth.

We note that our model reconciles the observed pattern of savings and private investments, in contrast to prior studies. When uncertainty spikes upward, our representative agent reduces private consumption in order to increase her precautionary savings. Simultaneously, private investment declines because the increase in private savings is dominated by a reduction of government savings, or, equivalently, by the higher government expenditure in investment goods, consistent with the data.
Given this encouraging fit, we run a counterfactual welfare analysis. Specifically, we computer welfare under the scenario in which government capital is not required for production reasons and is null. In our benchmark setting, the benefits of having access to public capital can be as high as 4% of life-time consumption. This number results solely from the ability of hedging exogenous uncertainty shocks and should be interpreted as an upper bond, as in our model we abstract away from uncertainty stemming from government policy (see, for example, Pastor and Veronesi (2012, 2013), Kelly et al. (2013), Fernandez-Villaverde et al. (2015a), and Baker et al. (2016)), lack of commitment (see, for example, Azzimonti et al. (2009) and Farhi et al. (2013)), and the nature of financing risk (see, among others, Lustig et al. (2008) and Berndt et al. (2012)).

**Related literature.** Our manuscript contributes to a recently growing literature that studies the real effects of uncertainty shocks (see, among others, Ramey and Ramey (1995), and more recently Bloom et al. (2007) and Bloom (2009)). We find that higher productivity volatility is associated with a relevant reallocation away from R&D and a decline in future growth. A general equilibrium model with endogenous growth and multiple sectors suggest that these features of the data may result from an efficient adjustment induced by volatility concerns.

More broadly, our analysis relates to the recent literature examining the role of uncertainty both in the data and in economic models (see, among others, Jones et al. (2005); Justiniano and Primiceri (2008); Basu and Bundick (2012); Jurado et al. (2014); Gilchrist et al. (2014); and Bloom et al. (2016)).

Fernandez-Villaverde et al. (2015b) study the real effect of uncertainty shocks to unproductive government expenditure and distorsionary taxation in a neoclassical model with exogenous growth. We differ from this study for (i) our novel empirical
evidence on investment reallocation; (ii) our focus on productive government expenditure; and (iii) our focus on R&D and endogenous growth.

Belo et al. (2013) and Belo and Yu (2013) examine the effects of government investment and spending on asset prices. Our work complements their findings and highlights a new trade off between growth and government capital in times of higher uncertainty. Both our empirical focus on heterogenous forms of capital and endogenous growth, and our attention to priced uncertainty shocks are distinct from the work of Baxter and King (1993).

According to our model, it is optimal for the government to expand its size in bad times, an outcome broadly consistent with that of new Keynesian models (for a recent example, see Christiano et al. (2011)). We differ from this literature for our risk-based approach and for our attention to the trade off between long-term growth and government size.

We note that Futagami et al. (1993) have been the first one to consider an endogenous growth model with productive government capital. We differ from their study in many dimensions, the most important being that we focus on a stochastic environment with time-varying uncertainty and recursive preferences.

[TO BE UPDATED and EXTENDED.]

In the next section, we show our main empirical evidence. Section 3 describes the model and its calibration. We summarize our main results in section 4 and run sensitivity analysis in section 5. Section 6 concludes.

2 Empirical Evidence

In this section we show our main empirical findings. We start by looking at stylized patterns of relative investment across private firms sorted according to their innova-
tion intensity. We then turn our attention to investment reallocation across private and government capital and use a VAR approach to isolate the role of uncertainty shocks on investment reallocation. Finally, we demonstrate the link between the relative size of government capital and long-run productivity growth.

Most of our data are well-known and their sources are standard and described in detail in Appendix A.

2.1 Reallocation Across Innovation-sorted Firms

This step of our empirical analysis links data on macroeconomic aggregates, stock returns, and firm-level fundamental accounting. We use stock return data from CRSP and fundamental accounting data from COMPUSTAT to construct a quarterly combined panel.\footnote{Our results are robust to considering a post-1975 sample, in which the most recent Financial Accounting Standards Board (FASB) accounting standards apply. These standards regard the rules to expense R&D activities.} For each calendar year, we construct stock return portfolios by sorting firms based on their R&D intensity measured as the ratio of R&D expenses to total assets.

We group firms that report R&D data into five portfolios with equal number of firms. In our baseline case, the extreme portfolios constitute at least 10\% of the total market capitalization, consistent with prior studies in the literature. We form these portfolios once for each year based on the previous year’s R&D intensity and record subsequent equally-weighted returns and investments during periods of stress. In table 1, we consider NBER recession periods, as well as periods of high integrated stock market returns volatility. Integrated volatility is a broad measure of uncertainty with two relevant advantages: (i) it is easy to compute (see Appendix A for details), and (ii) it is available on long samples.
Table 1: Reallocation and Innovation-Intensity

<table>
<thead>
<tr>
<th>Portfolio</th>
<th>Return</th>
<th>( \Delta I_{tot} )</th>
<th>( \Delta CAPX )</th>
<th>( \Delta R&amp;D_{Assets} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recessions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market</td>
<td>-1.3</td>
<td>-7.2</td>
<td>-9.7</td>
<td>-0.0</td>
</tr>
<tr>
<td>HML-R&amp;D</td>
<td>-4.3</td>
<td>-8.2</td>
<td>-13.4</td>
<td>-0.7</td>
</tr>
<tr>
<td>Low R&amp;D</td>
<td>2.9</td>
<td>-6.0</td>
<td>-6.1</td>
<td>-0.0</td>
</tr>
<tr>
<td>High R&amp;D</td>
<td>-1.4</td>
<td>-14.5</td>
<td>-19.5</td>
<td>-0.7</td>
</tr>
<tr>
<td><strong>Top-5% iVol</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market</td>
<td>-51.7</td>
<td>-2.3</td>
<td>-4.1</td>
<td>-0.2</td>
</tr>
<tr>
<td>HML-R&amp;D</td>
<td>-18.9</td>
<td>-9.4</td>
<td>-12.1</td>
<td>-2.3</td>
</tr>
<tr>
<td>Low R&amp;D</td>
<td>-56.8</td>
<td>-1.4</td>
<td>-1.5</td>
<td>0.0</td>
</tr>
<tr>
<td>High R&amp;D</td>
<td>-65.5</td>
<td>-10.7</td>
<td>-13.6</td>
<td>-2.3</td>
</tr>
<tr>
<td><strong>Top-10% iVol</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market</td>
<td>-20.3</td>
<td>-1.6</td>
<td>-2.9</td>
<td>-0.1</td>
</tr>
<tr>
<td>HML-R&amp;D</td>
<td>-19.1</td>
<td>-11.2</td>
<td>-15.7</td>
<td>-0.7</td>
</tr>
<tr>
<td>Low R&amp;D</td>
<td>-19.0</td>
<td>4.4</td>
<td>4.2</td>
<td>0.0</td>
</tr>
<tr>
<td>High R&amp;D</td>
<td>-34.7</td>
<td>-6.8</td>
<td>-11.4</td>
<td>-0.7</td>
</tr>
</tbody>
</table>

Notes: Market includes all COMPUSTAT firms in our sample with non-missing R&D expenses. Our quarterly sample starts in 1972 and ends in 2015. The Low (High) portfolio includes the bottom (top) 20% of R&D intensity-sorted firms and accounts for about 10% of total market capitalization. HML-R&D measures the difference of a variable across the High-intensity and the Low-intensity portfolios. The panel ‘Top-5% iVol’ (‘Top-10% iVol’) refers to months in which integrated US volatility has been in its historical top-5\(^{th}\) (top-10\(^{th}\)) percentile. \( \Delta I_{tot} \) (\( \Delta CAPX \)) refers to total investment (tangible capital) expenditures, as reported in COMPUSTAT.

Data about the Market are obtained by considering all firm with non-missing R&D data over our sample. HML-R&D refers to the difference in behavior of the variables of interest across the High- and Low-intensity portfolios. We interpret the figures for HML-R&D as being specific to innovative firms, as they are in excess of those observed for non-R&D intensive firms.

Our result confirm that innovative firms are more exposed to periods of economic stress in many dimensions. As well known in the literature, these firms suffer more sever capital losses than non-innovative firms. Our novel highlight refers to the relative reallocation of investment away from R&D-intensive firms. Even though all firms
cut down investment, High R&D intensive firms cut down both their tangible and total investments more severely.

Across all groups of firms, during periods of high uncertainty, R&D intensity declines. This observation is important because in many models of endogenous growth and innovation, R&D intensity is a leading indicator of medium-term growth. Hence uncertainty may anticipate periods of prolonged sluggish growth.

In the next section, we use macro data to account also for reallocations away from the private sector. Specifically, we introduce key facts about government investment goods and show that they are quantitatively relevant for the assessment of capital reallocation.

### 2.2 Government Capital and Economic Fluctuations.

Government capital data are reported in the National Income and Product Account (NIPA), according to criteria described in Bureau of Economic Analysis (2014). Examples of expenditures included in our government capital measure are provided in table 2. We include both tangible and intangible investment. We also consider local infrastructure like, for example, water and sewer systems. Our data are consistent with other sources explored by Aschauer (1988), Boskin et al. (1989), Peterson (1990), and Kamps (2004).

In figure 1, we depict the time-series of the share of gross government investment to total gross investment, as well as the relative share of the stock of government capital to total capital in the economy. Two key features are worthy of notice. First, government capital represents on average about 25% of total capital in the economy, i.e., a sizable portion. Second, the relative share of government investment is strongly countercyclical, as it tends to quickly increase during recession periods.
Table 2: Components of Government Gross Investment

<table>
<thead>
<tr>
<th>Component</th>
<th>Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structures</td>
<td>Buildings (residential, industrial, educational, hospital, and other)</td>
</tr>
<tr>
<td></td>
<td>Highways and streets</td>
</tr>
<tr>
<td></td>
<td>Sewer systems</td>
</tr>
<tr>
<td></td>
<td>Water systems</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
<tr>
<td>Equipment</td>
<td>Vehicles</td>
</tr>
<tr>
<td></td>
<td>Electronics</td>
</tr>
<tr>
<td></td>
<td>...</td>
</tr>
<tr>
<td>Intellectual property products</td>
<td>Software</td>
</tr>
<tr>
<td></td>
<td>R&amp;D</td>
</tr>
</tbody>
</table>

Notes: Component breakdown as seen in NIPA table 3.9.5. Examples are from Bureau of Economic Analysis (2014).

To better assess the countercyclicality of government capital, in figure 2 we focus on the average path of government investment and capital stock across recessions. In both panels, we consider data for NBER recession periods starting from 1950 so that we consider the same sample across quarterly and annual data. Including pre-1950 recessions would make our results for quarterly data even stronger. Our plots show that the reallocation toward government capital is both substantial and prolonged, as it often persists beyond the end of the recession.

Furthermore, there is something unique about government investment that goes above and beyond the countercyclical behavior of total government expenditure. During recession periods, government expenditure increases relative to total private expenditure (i.e., gross private investment plus consumption) mainly through the public investment channel (figure 3(a)).

This dynamic behavior has been even more pronounced during the Great Recession, with almost no sign of reversal three years after the beginning of the recession (figure 3(b)). The results in table 3 confirm and quantify these observations. Periods
Fig. 1. **Government Capital and Economic Fluctuations.** The left panel shows quarterly gross government investment \(I_g\) as a share of total domestic investment \(I_g + I_p\), which also includes private gross investment \(I_p\). The right panel shows the annual stock of government capital \(K_g\) as a share of the total domestic stock of capital \(K_g + K_p\), which also includes the private capital stock \(K_p\). Our data sources are detailed in Appendix A. For examples of government investment see table 2.

of elevated uncertainty are associated to a reallocation from private to government capital. According to our equilibrium model, government bond returns should proxy the returns of government capital. Under this assumption, the reallocation toward government capital comes with an appreciation of the latter, whereas private capital suffers a loss of value. Untabulated results confirm these results also when we consider 10-year and 30-year bonds.

Aggregate data confirm that periods of high uncertainty are associated to a decline in R&D intensity in both the private and government sector. Taken together, aggregate data and COMPUSTAT data suggest that innovation-oriented investments are penalized in periods of high uncertainty. Within the private sectors, investments are shifted toward low innovation-intensity firms. Furthermore, private investments are substituted by tangible government investments. Our data on returns suggest that this reallocation is consistent with an increased demand of safer assets, as both
government assets and private firms with low R&D intensity are less exposed to uncer-

tainty than R&D-intensive firms.

In order to better understand what drives this reallocation, in the next section we examine the role of uncertainty shocks through a VAR approach.

2.3 Government Capital and Uncertainty Shocks.

A broad measure of uncertainty. In order to evaluate the sources of the afore-

mentioned capital reallocation, we start by estimating the following VAR(1):

\[ Y_t = \mu_Y + \Phi Y_{t-1} + \Sigma u_t \]  

(1)
Fig. 3. Reallocation During Recessions. In the left panel, we report the average path of the variables of interest across the latest 10 NBER recessions starting from 1950. Time \( t = 1 \) is the first quarter of the recession. The right panel focuses on the Great Recession only (2007:Q4–2009:Q2). Total federal expenditure is denoted by \( G \). Total private expenditure is the sum of private consumption (\( C \)) and gross private investment (\( I_p \)). The subcomponent of government expenditure associated to gross government investment is denoted as \( I_g \). Our data sources are detailed in Appendix A.

<table>
<thead>
<tr>
<th>Sector</th>
<th>Return</th>
<th>( \Delta I_{tot} )</th>
<th>( \Delta CAPX )</th>
<th>( \Delta R&amp;D _\text{Assets} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Recessions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>-1.3</td>
<td>-5.4</td>
<td>-5.9</td>
<td>-0.01</td>
</tr>
<tr>
<td>Government**</td>
<td>7.0</td>
<td>0.8</td>
<td>0.7</td>
<td>-0.03</td>
</tr>
<tr>
<td><strong>Top-5% iVol</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>-51.7</td>
<td>-2.4</td>
<td>-2.8</td>
<td>-0.00</td>
</tr>
<tr>
<td>Government**</td>
<td>2.0</td>
<td>1.5</td>
<td>1.2</td>
<td>-0.01</td>
</tr>
<tr>
<td><strong>Top-10% iVol</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private</td>
<td>-20.3</td>
<td>-1.2</td>
<td>-1.4</td>
<td>-0.01</td>
</tr>
<tr>
<td>Government**</td>
<td>3.4</td>
<td>1.1</td>
<td>0.9</td>
<td>-0.01</td>
</tr>
</tbody>
</table>

Notes: The returns for the ‘Private’ sectors are obtained by including all COMPUSTAT firms in our sample with non-missing R&D expenses. The returns for ‘Government’ are from T-bills. Aggregate investment data are from the B.E.A. Total private (government) assets are measured using the total stock of private (government) capital reported in the NIPA tables. Our sample starts in 1972 and ends in 2015. The panel ‘Top-5% iVol’ (‘Top-10% iVol’) refers to months in which integrated US volatility has been in its historical top-5\(^{th}\) (top-10\(^{th}\)) percentile.
in which

\[ Y_t = \begin{bmatrix} \Delta a_t \\ iVol_t \\ I_{g,t}/(I_{p,t} + I_{g,t}) \end{bmatrix}, \tag{2} \]

where \( I_{g,t}/(I_{p,t} + I_{g,t}) \), \( \Delta a_t \), and \( iVol_t \), denote government gross investment share, productivity growth, and integrated volatility for stock market returns, respectively. Productivity captures shocks to the level of economic activity.

Throughout this study, we do not need to take a stand on causality across uncertainty and level shocks. We identify impulse responses through a lower diagonal Cholesky decomposition and point out that their pattern does not change whether level shocks or volatility shocks are ranked first. For the purpose of our analysis, both methods produce similar orthogonalized level and volatility shocks. Using our estimated VAR, we trace the response of the government investment share to both productivity and volatility shocks in figure 4(a). For robustness, we consider both quarterly and annual data.

Positive productivity shocks imply a relative shift of resources away from the public sector, whereas the opposite is true for adverse uncertainty shocks. Both of these adjustments are sizable and statistically significant over a 4-year horizon. Most importantly, focusing on the magnitude of the dynamic reallocation we note that uncertainty shocks are as relevant as level shocks.

The results depicted in figure 4(a) are based on a sample starting in 1969. We choose this starting date because our alternative measure of uncertainty, i.e., productivity volatility, is not available prior to that year. In Appendix B, we show that our results are unchanged when we use our longer quarterly sample starting in 1947 (see appendix figure B1).
This figure shows the response of gross government ($I_g$) and private investment ($I_p$) to both productivity growth and volatility shocks. The left panels refer to government investment as a share of total domestic investment. All results are based on the VAR specified in equations (1)–(2), in which we use stock market integrated volatility to measure uncertainty. In the right panels, investment series are HP filtered and replace the government investment share in our VAR. Our sources are detailed in Appendix A. Our sample starts in 1969 and ends in 2011. Data are quarterly unless otherwise specified. Confidence intervals are adjusted for heteroscedasticity.

Turning our attention to figure 4(b), we note that volatility shocks are associated to a significant increase in government investment and a simultaneous decline in private investment. Hence our reallocation evidence is not driven solely by private investment adjustments. With respect to positive level shocks, instead, both government and private investment increase. In this case, the decline of the government investment share is just a reflection of the stronger adjustment in private investment.
Productivity uncertainty. Integrated stock market volatility results from many
different economic phenomena that are not solely related to uncertainty shocks. As
an example, integrated volatility may be driven by sentiment shocks, or time-varying
market frictions. In order to focus on a fundamental measure of economy activity
uncertainty, we extract time-varying volatility from productivity growth.

Specifically, in the spirit of Bansal and Shaliastovich (2013), we form the following
array of forecasting variables

$$ F_t = [y_t(1), y_t(2), ..., y_t(6), \, inf_t, \, pd_t, \, iVol_t], $$

(3)

where $y(m)$ is the yield of a US Treasury bond with maturity $m$, $inf$ denotes inflation,
and $pd$ refers to the price-dividend ratio. We demean productivity growth ($\Delta a$)
through the following forecasting regression

$$ \Delta a_{t+1} = \mu + x_t + \epsilon_a_{t+1} $$

(4)

$$ x_t = b_x F_t $$

(5)

and filter expected volatility by specifying the following projection:

$$ |\epsilon_{a,t+1}| = vol_t + resid_{t+1} $$

(6)

$$ vol_t = b'_v + b_{vol} F_t. $$

(7)

We jointly estimate the system of equations (3)–(7) and report summary results
for both quarterly and annual data in table 4. A standard Wald test rejects the
null hypothesis that there is no predictability in productivity volatility. Both with
quarterly and annual data, our volatility measure is persistent and volatile.
Table 4: Productivity Uncertainty

<table>
<thead>
<tr>
<th>Data</th>
<th>Persistence of Log-Vol. $(\rho_v)$</th>
<th>Volatility of Log-Vol. $(\sigma_v)$</th>
<th>Wald Test $(H_0 : b_i^v = 0 \forall i)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarterly</td>
<td>0.075</td>
<td>0.15</td>
<td>25.55</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.05)</td>
<td>[0.00]</td>
</tr>
<tr>
<td>Annual</td>
<td>0.65</td>
<td>0.40</td>
<td>20.63</td>
</tr>
<tr>
<td></td>
<td>(0.32)</td>
<td>(0.52)</td>
<td>[0.01]</td>
</tr>
</tbody>
</table>

Notes: This table reports results from estimating the system of equations (3)–(7) augmented with the following representation for log-volatility

$$
\log(vol_t) = c_v + \rho_v \log(vol_{t-1}) + \sigma_v \epsilon_{v,t} + b_{v|\text{ar}} \epsilon_{a,t} + b_{v|\text{x}} \epsilon_{x,t},
$$

in which $\epsilon_{v,t}$ refers to a standardized volatility-specific shocks, as we control for both short-run productivity shocks ($\epsilon_{a,t}$) and growth news shocks ($\epsilon_{x,t}$). Numbers in parentheses are Newey-West adjusted standard errors. Numbers in square brackets are $p$-values for the null hypotheses that productivity volatility is constant ($H_0 : b_i^v = 0 \forall i = 1, ..., 9$).

We show our fitted volatility processes in figure 5 and make three remarks. First, our estimates replicate the time-pattern documented in the literature for other macro quantities, as we capture both the post-1980 Great Moderation and the subsequent turbulence period. Second, productivity volatility is countercyclical. Third, when we use annual data we detect more time-varying volatility than in the estimation with quarterly data. We conjecture that this is driven by the fact that annual data are less noisy than quarterly data. We find these results reassuring as they confirm that our productivity-based measure of uncertainty is reliable.

We proceed by estimating the VAR specified in equation (1) using the following vector of variables

$$
Y_t = \begin{bmatrix}
\Delta a_t \\
x_t \\
v_{ol_t} \\
I_{g,t}/(I_{p,t} + I_{g,t})
\end{bmatrix},
$$

15
where the productivity long-run component $x_t$ is added solely to control for growth news shocks.

As in the case of integrated volatility, uncertainty shocks promote a strong and persistent reallocation of resources toward public capital. This effect is even more pronounced when we focus on annual data, as productivity volatility swings are more sizable at an annual frequency. The prediction of our annual data VAR are subject to larger confidence intervals than those from our quarterly data, but this is not surprising given our short-sample. Both with quarterly and annual data, adverse uncertainty shocks promote a reallocation that is significant at least over a 2-year horizon.

In figure 6(b), we replace our measure of expected volatility with the residual of the estimation of equations (6)–(7). We note that there is no significant reallocation in this case, implying that what really matters for investment flows is the extent of expected long-term uncertainty. Most importantly, in figure 7 we show that our reallocation results apply also to the subcomponent of aggregate investment related

**Fig. 5. Productivity uncertainty.** This figure shows quarterly and annual conditional volatility of productivity growth. We recover these measures by jointly estimating the system of equation (3)–(7) by GMM. Our sources are detailed in Appendix A. Our sample ranges from 1969:Q1 to 2011:Q1 (1969-2011) for our quarterly (annual) data.
Fig. 6. Response of Government Investment Share (productivity volatility).
The figure in panel (a) shows the response of the government investment share to both productivity growth and volatility shocks. Gross government investment ($I_g$) is divided by total domestic investment ($I_g + I_p$), which also includes private gross investment ($I_p$). All results are based on the VAR specified in equations (1) and (8), in which we measure uncertainty by productivity volatility estimated as in equations (3)–(7). The panels on the left (right) are based on quarterly (annual) data. In panel (b), we replace expected long-run volatility with the residual of equation (6). Our sources are detailed in Appendix A. Our sample starts in 1969 and ends in 2011. Confidence intervals are adjusted for heteroscedasticity.

to R&D activities. This result is obtained after augmenting our VAR with the Baa spread, a common index of credit conditions. To the extent to which R&D fosters innovation and growth, these results suggest that expansions of government capital may come at the cost of slowing down future growth.

Given these considerations, in the next section we explore the link between relative size of government and private capital and long-term growth. We are interested in understanding whether there is a correlation between uncertainty shocks, relative contraction of the private sector, and sluggish growth.
Fig. 7. Reallocation and R&D. This figure shows the response of government investment ($I_g$) and private R&D investment ($I_{R&D}$). All results are based on the VAR specified in equations (1) and (8), in which (i) we measure uncertainty by productivity volatility estimated as in equations (3)–(7), (ii) replace the last variable with HP-filtered investment levels, and (iii) we control for credit condition by adding the Baa spread. Our sources are detailed in Appendix A. Our quarterly sample starts in 1969 and ends in 2011. Confidence intervals are adjusted for heteroscedasticity.

2.4 Relative Government Size and Long-Run Growth.

In this section, we investigate whether the relative size of government capital is related to future productivity growth. Let $\Delta a_{t,t+10}$ be the 10-year-ahead cumulative aggregate
productivity growth at time $t$. The results depicted in figure 8 suggest the existence of a negative correlation between government capital share and future long-term growth.

In order to formally test this negative link, we run the following forecasting regression:

$$\frac{1}{10} \Delta a_{t,t+9} = \mu + b_x F_t + b_g \frac{k_{g,t}}{k_{tot,t}} + FinControls_t + \epsilon_{a,t+1} \quad (9)$$

where $F_t$ refers to the forecasting variables described in equation (3), and $\frac{k_{g,t}}{k_{tot,t}}$ denotes the public-to-total capital stock ratio. The goal of this auxiliary regression is to unveil a possible connection between the size of public capital and 10-year growth above and beyond what is captured by the procedure in Bansal and Shaliastovich (2013). Furthermore, we control for credit and liquidity conditions by considering also the

---

**Fig. 8. Relative Size of Government Capital and Future Growth.** The vertical axis refers to 10-year forward moving average for aggregate productivity growth ($\frac{\Delta a_{t,t+10}}{10}$). Our data sources are detailed in Appendix A.
Table 5: Relative Government Size and Long-Run Growth

<table>
<thead>
<tr>
<th>Variables</th>
<th>(1)</th>
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<th>(3)</th>
<th>(4)</th>
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<tbody>
<tr>
<td>$\frac{k_g}{k_{total}}$</td>
<td>-0.28***</td>
<td>-0.24***</td>
<td>-0.26***</td>
<td>-0.12***</td>
</tr>
<tr>
<td></td>
<td>(0.05)</td>
<td>(0.06)</td>
<td>(0.06)</td>
<td>(0.04)</td>
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<tr>
<td>Predicting Factors</td>
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<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Adj $R^2$</td>
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<td>0.51</td>
<td>0.32</td>
<td>0.22</td>
</tr>
<tr>
<td>Adj $R^2$ w/o $\frac{k_g}{k_{total}}$</td>
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<td>0.41</td>
<td>0.12</td>
<td>0.00</td>
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</table>

Notes: This table reports the estimated coefficients $\hat{b}_g$ for the regression described in equation (9). $\frac{k_g}{k_{total,t}}$ denotes the public-to-total capital stock ratio. The other forecasting variables in $F_t$ are specified in equation (3). Our controls for financial conditions always include the national financial conditions indexes of the Chicago Fed. Our sources are detailed in Appendix A. Our annual sample starts in 1969 and ends in 2011. Confidence intervals are adjusted for heteroscedasticity. One, two, and three asterisks denote 10%, 5%, and 1% significance, respectively.

Table 5 shows the results from estimating (9) across different combinations of controls. Across all cases, the public-to-total capital ratio has strong and negative predictive power, meaning that periods in which public capital is expanded relative to total capital lead times of sluggish long-term growth. Furthermore, the increment in the adjusted $R^2$ due to the government capital ratio is always substantial.

In an attempt to corroborate further the relevance of the link between government capital size and productivity growth, we also estimate a VAR with our 10-year-ahead cumulative aggregate productivity growth and the government-to-total capital ratio over the 1952:q1–2005:q4 sample. We then use the VAR to form dynamic forecasts of long-term productivity growth under two scenarios. In the first scenario, we take the level of the government capital share from the data over the remaining of our
Fig. 9. Relative Size of Government Capital and Future Growth (II). The dashed line refers to 10-year forward moving average for aggregate productivity growth ($\frac{\Delta a_{t+10}}{10}$) over the 1952:q1–2005:q4 sample. The solid line shows the prediction of a VAR with aggregate productivity growth, government capital share, and financial controls (the national financial conditions indexes of the Chicago Fed and the Baa spread). The dotted line refers to a counterfactual scenario in which the government capital share is set to its own long-run mean in 2006:q1. Our data sources are detailed in Appendix A.

Sample (2006:q1–2015:q4). In the second case, instead, we set the capital ratio from 2006:q1 onward equal to its unconditional mean so that it plays no role in the future forecasted pattern. As shown in figure 9, the increased size of government capital observed during the Great Recession capital may be a leading indicator of a sizable and persistent growth slow-down.

These empirical findings have a broad and significant implication, namely, they suggest that the reallocation to the government sector may be costly because it is typically followed by prolonged growth slow-downs. In the next section, we explain...
these findings in a production economy in which the representative agent has an explicit fear toward uncertainty and government capital is, in equilibrium, a safe asset which offers less volatility at the cost of lower growth.

3 The Model

We start by describing the representative household problem and then describe both the private and public production sectors. The model is based on Comin and Gertler (2006) and it features a government-owned production sector.

3.1 Household problem

The objective of the representative agent is to maximize her utility

\[
U_t = \left( (1 - \delta) \tilde{C}_t^{1 - \frac{1}{\psi}} + \delta \left( E_t [U_{t+1}^{1 - \gamma}] \right)^{1 - \frac{1}{\psi}} \right)^{\frac{1}{1 - \psi}}
\]

where the consumption bundle \( \tilde{C}_t \) is

\[
\tilde{C}_t = C_t - \bar{\omega}_{t,p} \frac{SL_t L_{p,t}^{\omega_l}}{\omega_l} - \bar{\omega}_{t,g} \frac{SL_t L_{g,t}^{\omega_l}}{\omega_l},
\]

in which \( C_t \) denotes the consumption of the final good, \( L_{p,t} \) is the labor supply in private sector, and \( L_{g,t} \) is the labor supply in government sector. To ensure balance growth with Greenwood et al. (1988) preferences, we introduce an exogenous preference shock process, \( SL_t \), cointegrated with productivity. Specifically, we define:

\[
sla_t := \frac{SL_t}{A_t}
\]
and assume

\[ sla_t = (1 - \theta_{sla}) \mu + (1 - \theta_{sla})(sla_{t-1} - \Delta a_t). \]

We set \( \theta_{sla} \approx 1 \) so that \( SL_t \) mimics an exogenous linear trend.

The budget constraint of the representative household is:

\[
C_t + T_t + Z_t V_t^{ex} = Z_{t-1}(V_{p,t}^{ex} + D_t) + (w_{p,t}L_{p,t} + w_{g,t}L_{g,t})/\tilde{p}_t, \tag{11}
\]

where \( T_t \) is a lump-sum transfer from the household to the government; \( Z_t \in [0, 1] \) represents the percentage ownership of private capital; \( V_t^{ex} \) is the ex-dividends value of private capital; \( D_t \) is the corporate payout; \( w_p \) is the wage paid by the private firm; and \( w_g \) is the wage paid by the government. As described in detail in the next section, \( \tilde{p}_t \) is the relative price of the final good with respect to the numeraire (government) good. This change of unit is required because all variables are expressed in terms of the final good.

**Optimality.** The optimal investment strategy implies that:

\[
V_t^{ex} = E_t [M_{t+1}(V_{t+1}^{ex} + D_{t+1})],
\]

where \( M_{t+1} \) is the IMRS of the agent in final consumption units. In what follows, we often use the IMRS in government-good units,

\[
M_{t+1}^g \equiv M_{t+1} \frac{\tilde{p}_t}{\tilde{p}_{t+1}}.
\]

The optimal supply of labor in private and public sectors implies:

\[
w_{p,t}/\tilde{p}_t = \omega_{t,p} SL_t L_{t+1}^{\omega_{t} - 1}
\]
\[ w_{g,t} / \tilde{p}_t = \bar{\omega}_{l,g} SL_t L_{g,t}^{\omega_l - 1}. \]

### 3.2 Final good producer

The final good in the economy is a bundle of private goods, \( Y_{p,t} \), and public goods, \( Y_{g,t} \)

\[
Y_t = \left[ \bar{\omega}_t Y_{p,t}^{1 - \frac{1}{\tau}} + (1 - \bar{\omega}_t) Y_{g,t}^{1 - \frac{1}{\tau}} \right]^{\frac{1}{1 - \frac{1}{\tau}}}. \tag{12}
\]

The elasticity of substitution between these two goods is determined by \( \tau \). The relative demand of the private good with respect to the public good is also determined by the possibly time-varying preference process \( \omega_t \). For parsimony, we assume that

\[
\omega_t = \omega e^{\phi_v v_{t-1}},
\]

where \( v_{t-1} \) is the time-varying volatility of productivity, and \( \phi_v \) is a non-positive constant. This expression captures the idea that public goods may be more desirable in high-uncertainty periods. In our sensitivity analysis, we show that most of our results do not require the presence of a preference shocks, i.e., they hold even when \( \phi_v = 0 \).

We assume the existence of a competitive producer that solves the following profit maximization problem taking prices as given:

\[
\max_{Y_{p,t}, Y_{g,t}} \tilde{p}_t Y_t - p_t Y_{p,t} - Y_{g,t}, \tag{13}
\]

where the price of the government good is normalized to one (numeraire). Optimality implies:

\[
\frac{\omega_t}{1 - \omega_t} \left( \frac{Y_{p,t}}{Y_{g,t}} \right)^{-\frac{1}{\tau}} = p_t. \tag{14}
\]
The relative price of the final good w.r.t the numeraire good:

\[ \tilde{p}_t \equiv \frac{\partial Y_{g,t}}{\partial Y_t} = \frac{1}{1 - \omega_t} \left( \frac{Y_{g,t}}{Y_t} \right)^{\frac{1}{\tau}}. \]

### 3.3 Private sector

**Private final good.** The private firm that produces the private final good has monopolistic power. The private firm has also access to the same technology of the public firm and hence it could produce the public good as well. Since the price of the public good is set equal to its marginal cost, there is no scope for positive profits creation, i.e., marginal profits are null and hence the firm is indifferent between utilizing the public technology or not. Without loss of generality, we assume that the private firm specializes in the production of the private good.

The production function of the private final good is:

\[ F_{p,t} = (K_{p,t}^{\alpha_p} (\Omega_{p,t} L_{p,t})^{1-\alpha_p})^{1-\xi} G_t^\xi, \] (15)

where the composite \( G_t \) is defined as

\[ G_t \equiv \left[ \int_0^{N_t} X_{i,t} \, dt \right]^{\frac{1}{\tau}}, \] (16)

\( X_{i,t} \) is the quantity of the intermediate good \( i \in [0, N_t] \), and \( N_t \) is the total mass of intermediate good varieties. Since each intermediate good requires a patent, \( N_t \) also measures the total mass of patents in use at date \( t \). The exogenous stationary process
of private firm productivity is $\Omega_{p,t} = e^{a_{p,t}}$, where $a_{p,t}$ follows an AR(1) process subject to volatility shocks, $\epsilon_{v,t}$:

$$a_{p,t} = (1 - \rho)\bar{a} + \rho a_{p,t-1} + \epsilon_{v,t}^v \sigma_{a,t}$$

$$v_t = \rho_v v_{t-1} + \sigma_v \epsilon_{\sigma,t} + \beta_{v,a} \epsilon_{a,t}$$

$$\epsilon_{\omega,t}, \epsilon_{\sigma,t} \sim \text{i.i.d.} N(0,1).$$

The parameter $\beta_{v,a}$ captures contemporaneous correlation across level and volatility shocks. In what follow, we refer to level shocks as short-run shocks, as they determine most of the variance of the growth dynamics over the short-run. Over longer horizon, capital reallocation is the main driver of growth.

We assume that the private firm buys production inputs (investment goods $I_{p,t}$, labor $L_{p,t}$, and intermediate goods $X_{i,t}$) in a competitive way, that is, by taking their price as given. Hence the problem of the private firm is as follows:

$$V_{p,t} = \max_{L_{p,t}, I_{p,t}, Y_{p,t}, K_{p,t+1}, X_{i,t}} \frac{\omega_t}{1 - \omega_t} \left( \frac{Y_{p,t}}{Y_{g,t}} \right)^{-\frac{1}{\gamma}} Y_{p,t} - \bar{p}_t I_{p,t} - w_p L_{p,t}$$

$$- p_t \left[ \int_{0}^{N_t} P_{t,t} X_{i,t} \, dt \right] + E_t[M_{t+1}^q V_{p,t+1}]$$

subject to

$$Y_{p,t} \leq F_{p,t} \quad (\lambda_{p,t})$$

$$K_{p,t+1} \leq \left( 1 - \delta + \Gamma_{p,t} \left( \frac{I_{p,t}}{K_{p,t}} \right) \right) K_{p,t} \quad (\eta_{p,t}),$$

26
where $\lambda_{p,t}$ is the shadow marginal cost, and $q_{p,t}$ is the shadow value of private capital.

The adjustment cost function is specified as in Jermann (1998):

$$\Gamma_{p,t} = \frac{\alpha_{p,1}}{1 - \frac{1}{\xi_p}} \left( \frac{I_{p,t}}{K_{p,t}} \right)^{1 - \frac{1}{\xi_p}} + \alpha_{p,0},$$

and the optimality condition with respect to $I_{p,t}$ pins down the marginal value of private capital:

$$q_{p,t} = \frac{\tilde{p}_t}{\Gamma_{p,t}}$$

(18)

The optimal demand of labor implies

$$\frac{w_{p,t}}{p_t} = (1 - 1/\tau)(1 - \alpha_p)(1 - \xi) \frac{Y_{p,t}}{I_{p,t}};$$

and the optimal condition with respect to $K_{p,t+1}$ is:

$$q_{p,t} = E_t \left[ M^0_{t+1} \frac{\partial V_{p,t+1}}{\partial K_{p,t+1}} \right]$$

(19)

where by envelope theorem we have:

$$\frac{\partial V_{p,t}}{\partial K_{p,t}} = (1 - 1/\tau)p_t\alpha_p(1 - \xi) \frac{Y_{p,t}}{K_{p,t}} + \left( 1 - \delta + \Gamma_{p,t+1} - \frac{I_{p,t+1}}{K_{p,t+1}} \Gamma'_{p,t+1} \right) q_{p,t+1}.$$  

(20)

The optimal demand of $X_{i,t}$ implies

$$P_{i,t} = (1 - 1/\tau + 1/\tau \int_0^{N_t} \frac{P_{i,t}X_{i,t}}{Y_{p,t}} \frac{dy_{i,t}}{X_{i,t}}) \frac{\partial Y_{p,t}}{\partial X_{i,t}}$$

(21)

where

$$\frac{\partial Y_{p,t}}{\partial X_{i,t}} = \xi (K_{p,t}(\Omega_{p,t}L_{p,t})^{1-\alpha_p})^{-1-\xi} \left[ \int_0^{N_t} X_{i,t}^{\nu} \frac{dy_{i,t}}{X_{i,t}} \right]^{\frac{\xi}{\nu} - 1}.$$
Intermediate Goods. Intermediate good producers can generate one unit of their own good by buying one unit of the private good at market price $p_t$. They have monopoly power and choose $P_{i,t}$ to maximize their profits, $\Pi_{i,t}$, each period:

$$\max_{P_{i,t}} \Pi_{i,t} \equiv \max_{P_{i,t}} p_t \cdot [P_{i,t} \cdot X_{i,t}(P_{i,t}) - X_{i,t}(P_{i,t})].$$

Since $\Pi_{i,t}$ is measured in public good units, the value $V_{i,t}$ of owning exclusive rights to produce intermediate good $i$ is:

$$V_{i,t} = \Pi_{i,t} + (1 - \phi)E_t[M_{i+1}V_{i,t+1}], \quad (22)$$

where $\phi$ is the probability that a patent becomes obsolete.

Aggregation. In our symmetric equilibrium,

$$P_{i,t} \equiv P_t = \frac{1}{\nu}, \quad (23)$$

$$X_{i,t} \equiv X_t = \left( \frac{\xi \nu}{1 - \xi / \tau} \left( K_{p,t}^{\alpha_p} (\Omega_{p,t} L_{p,t}^{1 - \alpha_p})^{1 - \xi} N_t^{\xi - 1} \right)^{1 - \xi} \right)^{\frac{1}{1 - \xi}} \quad (24)$$

Under the restriction $\alpha + \frac{\xi - \xi}{1 - \xi} = 1$, the production function of private good sector can be written as:

$$Y_{p,t} = Z_{p,t} K_{p,t}^{\alpha_p} L_{p,t}^{1 - \alpha} \quad (25)$$

where

$$Z_{p,t} \equiv A(\Omega_{p,t} N_t)^{1 - \alpha}, \quad (26)$$

is an endogenous productivity process that grows with the stock of patents $N_t$, and whose initial level, $A \equiv \left( \xi \nu^{1 - 1/\tau} \right)^{1 - \xi / \tau}$, depends on the extent of competition as
determined by the elasticities $\tau$ and $\xi$. Like $\Omega_{p,t}$, measured productivity features time-varying volatility.

**Innovators.** Innovators develop new patents that are sold to the intermediate good producers in a competitive way. As a result, at the equilibrium, the price of a new patent is $V_{i,t}$. The law of motion of the intangible capital stock $N_t$, to innovation as follows:

$$
N_{t+1} = \vartheta_t S_t + (1 - \phi)N_t,
$$

(27)

where $S_t$ denotes R&D expenditures (in terms of the final good) and $\vartheta_t$ represents the productivity of the R&D sector that is taken as exogenous by the R&D sector. In the spirit of Comin and Gertler (2006), we assume that this technology coefficient involves a congestion externality effect

$$
\vartheta_t = \chi \left( \frac{N_t}{S_t} \right)^{1-\eta},
$$

(28)

where $\chi > 0$ is a scale parameter and $\eta \in [0, 1]$ is the elasticity of new patents with respect to R&D. This specification captures the notion that concepts already discovered make it easier to come up with new ideas, $\partial \vartheta / \partial N > 0$, and that R&D investment has decreasing marginal returns, $\partial \vartheta / \partial S < 0$. The free-entry condition in the R&D sector implies that

$$
E_t[M^0_{t+1} V_{t+1}](N_{t+1} - (1 - \phi)N_t) = \tilde{p}_t S_t,
$$

(29)

where $\tilde{p}_t$ is the price of the intermediate good. For a similar reason, the optimality condition for R&D is $\frac{1}{\vartheta_t} = E_t[M_{t+1} V_{t+1}]$. Absent the congestion externality, this becomes $1 = E_t[M_{t+1} V_{t+1}]$, a result analogous to $q$-theory, in which case the absence of adjustment cost fixes marginal $Q$ at unity.

---

\footnote{Similarly, this congestion externality can be thought of as giving rise to adjustment costs to investment in intangible capital, that is, R&D. We will later see that the optimality condition for R&D is $\frac{1}{\vartheta_t} = E_t[M_{t+1} V_{t+1}]$. Absent the congestion externality, this becomes $1 = E_t[M_{t+1} V_{t+1}]$, a result analogous to $q$-theory, in which case the absence of adjustment cost fixes marginal $Q$ at unity.}
that is, the expected revenue from selling new patents must equal the incurred costs, or equivalently,

\[
\frac{\tilde{p}_t}{\vartheta_t} = E_t[M_{t+1}^g V_{t+1}].
\]

### 3.4 Government sector

The public firm provides its own good in a competitive fashion. The public firm uses labor, \( L_{g,t} \), and final goods to accumulate government capital, \( K_{g,t} \), and it solves the following dynamic problem:

\[
V_{g,t} = \max_{Y_{g,t}, K_{g,t+1}, L_{g,t}, I_{g,t}} Y_{g,t} - \tilde{p}_t I_{g,t} - w_{g,t} L_{g,t} + E_t[M_{t+1}^g V_{g,t+1}]
\]

subject to

\[
Y_{g,t} \leq F_{g,t} = \chi_g Z_{p,t} K_{g,t}^{\alpha_g} L_{g,t}^{1-\alpha_g} \quad (\lambda_{g,t})
\]

\[
K_{g,t+1} \leq \left( 1 - \delta + \Gamma_{g,t} \left( \frac{I_{g,t}}{K_{g,t}} \right) \right) K_{g,t} \quad (q_{g,t}),
\]

where \( \lambda_{g,t} \) is the shadow marginal cost of the government good, \( q_{g,t} \) is the shadow value of government capital, and the parameter \( \chi_g \) captures the measured gap in the level of measured public and private productivity. The adjustment cost function is defined as follows,

\[
\Gamma_{g,t} \left( \frac{I_{g,t}}{K_{g,t}} \right) = \frac{\alpha_g}{1 - \frac{1}{\xi_g}} \left( \frac{I_{g,t}}{K_{g,t}} + 1 \right)^{1 - \frac{1}{\xi_g}} + \alpha_{g,0},
\]

and allows for reversibility of government investment.\(^3\) This assumption captures the ability of the private sector to use infrastructure generated by the government.

\(^3\)The constant \( \alpha_{g,0} \) is set so that at the deterministic steady state \( \frac{I_g}{K_g} = \Gamma_g \). The coefficient \( \alpha_{g,1} \) is set so that at the deterministic steady state \( \Gamma_g = 1 \).
The optimality condition with respect to $Y_g$ implies that

$$\lambda_{g,t} \equiv 1,$$

i.e., the marginal cost must be equal to the price of the good. As a result, the optimal demand of labor implies

$$w_{g,t} = F_{g,t},$$

The optimality condition with respect to $I_{g,t}$ pins down the marginal value of public capital:

$$q_{g,t} = \frac{\tilde{p}_t}{\Gamma_{g,t}},$$

where $\tilde{p}_t$ accounts for the fact that investment is made using the final good. The optimality with respect to $K_{g,t+1}$ is

$$q_{g,t} = E_t \left[ M_{g,t+1} \frac{\partial V_{g,t+1}}{\partial K_{g,t+1}} \right]$$

$$= E_t \left[ M_{g,t+1} \left( F_{g,K_{g,t+1}} + \left( 1 - \delta + \Gamma_{g,t+1} - \frac{I_{g,t+1}}{K_{g,t+1}} \right) q_{g,t+1} \right) \right].$$

We think of the government sector as a low innovation-intensity sector. Subject to common comparability limitations across NIPA and COMPUSTAT data, this assumption is consistent with our data (see figure B2).

### 3.5 Payout Flows

The total private pay-out (in numeraire units) is

$$\tilde{p}_t D_t = p_t(Y_{p,t} - N_{t}X_{t}) - w_{p,t}L_{p,t} - (\tilde{p}_t I_{p,t} + \tilde{p}_t S_t),$$
that is, private GDP net of labor costs and private investments. As a result, $V^{ex}$ captures the value of both tangible and intangible private assets. The government payout is positive when the tax flow is negative, i.e., when the agent receives a net subsidy. Similarly to the private payout computations, in numeraire units, we have

$$-\tilde{p}_t T_t = Y_{g,t} - w_{g,t} N_{g,t} - \tilde{p}_t I_{g,t} \quad (34)$$

$$= \alpha_g Y_{g,t} - \tilde{p}_t I_{g,t}.$$

### 3.6 Calibration and Solution Method

We report our quarterly calibration in table 6. Many of the parameters are standard. The preference parameters are set in the spirit of the long-run risk literature. See, among others, Bansal and Yaron (2004).

Both the tangible capital income share and the depreciation rate of tangible capital are set to the same values across sectors. We choose numbers as in Croce (2014). We also set the elasticity of the adjustment cost functions to be the same. We choose a moderate value that lets investment be as volatile as in the data.

In the bundle that aggregates private and government goods, the weight $\omega$ is chosen to match the relative size of private and government investment. The coefficient $\phi_v$ is set to zero because we consider the presence of this shock only in our sensitivity analysis. The elasticity of substitution $\tau$ is set to have a total profit share comparable to the data. The parameters that determine the innovation activity in the model are set in the spirit of Comin and Gertler (2006) and Kung and Schmid (2012). Our innovators have stronger mark ups than other private producers, consistent with our COMPUSTAT data. The scaling parameter $\chi$ is set to have an annual average growth rate of 1.9%.
### Table 6: Benchmark Calibration

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</tr>
</thead>
<tbody>
<tr>
<td>Intangible Capital Share ( \xi )</td>
<td>0.49</td>
</tr>
<tr>
<td>Tangible Capital Share ( \alpha_p = \alpha_g )</td>
<td>0.3</td>
</tr>
<tr>
<td>Capital Depreciation Rate ( \delta_p = \delta_s )</td>
<td>0.06/4</td>
</tr>
<tr>
<td>Adjustment Cost Elasticity ( \xi_p = \xi_g )</td>
<td>3.5</td>
</tr>
<tr>
<td>Elasticity of Substitution Across Interm. Goods ( \nu^{-1} )</td>
<td>1.73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Innovation</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Intangible Capital Congestion, Scale Parameter ( \chi )</td>
<td>0.128</td>
</tr>
<tr>
<td>Intangible Capital Congestion, Elasticity ( \eta )</td>
<td>0.83</td>
</tr>
<tr>
<td>Patent Survival Rate ( 1 - \phi )</td>
<td>0.96</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Productivity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productivity Persistence ( \rho )</td>
<td>0.98</td>
</tr>
<tr>
<td>Productivity Volatility ( \sigma )</td>
<td>0.032/4</td>
</tr>
<tr>
<td>Relative Log-Volatility Persistence ( \rho_v )</td>
<td>0.74</td>
</tr>
<tr>
<td>Volatility of Relative Log-Volatility ( \sigma_v )</td>
<td>0.15</td>
</tr>
<tr>
<td>Relative Log-Volatility Short Run Exposure ( \beta_{v,a} )</td>
<td>-3.5</td>
</tr>
<tr>
<td>Average Government Gap ( \xi_g )</td>
<td>65%</td>
</tr>
</tbody>
</table>

**Notes:** This table reports our benchmark quarterly calibration.

Productivity is calibrated according to our quarterly data. Both the persistence and the magnitude of time-varying volatility are consistent with our confidence intervals reported in table 4. The parameter \( \beta_{v,a} \) accounts for the negative correlation between relative volatility and short-run shocks and is set according to the data to
In untabulated sensitivity analysis, we find that this parameter plays no crucial role.

Private and public productivity share the same dynamics, although public productivity is set to a lower average level. This is consistent with the data provided by the BEA. The model is solved with a third-order perturbation method.

4 Results

In this section, we use our benchmark model to study both new unconditional moments and to quantify the benefits of government capital through a counterfactual analysis. We also show the relevance of both recursive preferences and volatility shocks to generate the reallocation observed in the data.

4.1 Benchmark Model

The mechanism. In figure 10, we depict the response of variables of interest to both short-run productivity shocks and volatility shocks. We note several points. First, with respect to a short-run shock, our model behaves similarly to a standard production economy model, as private consumption, total labor, private investments, and output simultaneously expand. Because of decreasing marginal returns from R&D investments, the increase in R&D let the value of patents ($V_t$) increase. Similarly, capital adjustment costs determine and increase in the shadow value of private tangible capital ($q_{pt}$). At the equilibrium, there is a reallocation away from the private sector that is associated to a decline in the shadow value of government capital ($q_{gt}$).

An adverse volatility shock, instead, produces a contraction in private economic activity and promotes a reallocation toward government capital. Consistent with the
Fig. 10. Impulse Responses. This figure shows percentage deviations from steady state. Our benchmark calibration is reported in table 6. The dashed line refers to the model with no time-varying volatility ($\sigma_v = 0$).

data, both private consumption and private investment fall. In this case, thanks to the reallocation effect the value of public capital increases and hence provides an hedge against volatility. The value of private capital, in contrast, decreases sharply because
the present value of rents are very sensitive to volatility shocks and, equivalently, discount rate shocks.
<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Benchmark</th>
<th>PS (φv = -0.015)</th>
<th>No Vol (σv = 0)</th>
<th>CRRA (γ = 10 )</th>
<th>CRRA (γ = 0.5 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ(Δy) (%)</td>
<td>4.85</td>
<td>(0.90)</td>
<td>4.81</td>
<td>4.81</td>
<td>4.51</td>
<td>3.88</td>
</tr>
<tr>
<td>σ(Δc)/σ(Δy)</td>
<td>0.61</td>
<td>(0.11)</td>
<td>0.68</td>
<td>0.78</td>
<td>0.66</td>
<td>1.08</td>
</tr>
<tr>
<td>σ(Δitot)/σ(Δy)</td>
<td>2.14</td>
<td>(0.11)</td>
<td>1.70</td>
<td>1.70</td>
<td>1.67</td>
<td>0.81</td>
</tr>
<tr>
<td>σ(Δs) (%)</td>
<td>10.20</td>
<td>(1.88)</td>
<td>8.29</td>
<td>8.41</td>
<td>7.72</td>
<td>3.90</td>
</tr>
<tr>
<td>E [(Ip + S)/Y] (%)</td>
<td>15.06</td>
<td>(0.79)</td>
<td>31.45</td>
<td>31.20</td>
<td>31.53</td>
<td>19.71</td>
</tr>
<tr>
<td>σ((Ip + S)/Y) (%)</td>
<td>3.41</td>
<td>(0.67)</td>
<td>2.57</td>
<td>2.53</td>
<td>2.40</td>
<td>0.30</td>
</tr>
<tr>
<td>ρ(Δc, Δ ln(Ip + S))</td>
<td>0.84</td>
<td>(0.41)</td>
<td>0.81</td>
<td>0.82</td>
<td>0.81</td>
<td>0.99</td>
</tr>
<tr>
<td>E [Ig/Y] (%)</td>
<td>5.35</td>
<td>(0.51)</td>
<td>6.21</td>
<td>6.16</td>
<td>6.28</td>
<td>2.51</td>
</tr>
<tr>
<td>σ(Ig/Y) (%)</td>
<td>2.79</td>
<td>(1.00)</td>
<td>1.73</td>
<td>2.01</td>
<td>1.49</td>
<td>0.35</td>
</tr>
<tr>
<td>E [Kp + Kg] (%)</td>
<td>25.46</td>
<td>(0.54)</td>
<td>35.54</td>
<td>35.56</td>
<td>35.65</td>
<td>29.00</td>
</tr>
<tr>
<td>E [LEV] (%)</td>
<td>5.04</td>
<td>(1.98)</td>
<td>6.03</td>
<td>6.07</td>
<td>6.06</td>
<td>2.15</td>
</tr>
<tr>
<td>σ(LEV) (%)</td>
<td>19.72</td>
<td>(1.78)</td>
<td>16.42</td>
<td>16.47</td>
<td>15.92</td>
<td>13.50</td>
</tr>
<tr>
<td>E [r^g,LEV] (%)</td>
<td>0.00</td>
<td></td>
<td>-0.01</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
</tr>
<tr>
<td>σ(r^g,LEV) (%)</td>
<td>0.18</td>
<td></td>
<td>0.20</td>
<td>0.06</td>
<td>0.13</td>
<td>0.11</td>
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<tr>
<td>E [HML-RE^D,LEV] (%)</td>
<td>5.27</td>
<td>(3.74)</td>
<td>8.27</td>
<td>9.09</td>
<td>7.63</td>
<td>2.31</td>
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<tr>
<td>E [r^f] (%)</td>
<td>0.49</td>
<td>(0.50)</td>
<td>0.86</td>
<td>0.85</td>
<td>0.88</td>
<td>10.20</td>
</tr>
<tr>
<td>σ(r^f) (%)</td>
<td>2.75</td>
<td>(0.48)</td>
<td>1.95</td>
<td>1.86</td>
<td>0.87</td>
<td>1.91</td>
</tr>
</tbody>
</table>

Notes: Empirical moments are computed using annual data from 1929 to 2014. All data sources are discussed in Appendix A. Numbers in parentheses are standard errors adjusted for heteroscedasticity. The entries for the model are obtained by repetitions of small samples. Our baseline calibration is detailed in table 6. ‘PS’ denotes the model with preference shocks. ‘No vol’ denotes the model with no volatility shocks. ‘CRAA’ refers to a configuration with time-additive preferences.
To better quantify the performance of our model, in table 7 we show a comprehensive list of moments generated through simulations. The top portion of the table shows standard moments for private macro aggregates. Our model matches very well all these well known figures, except the average share of total private investment which is too high due to intangible investment. We note, however, that McGrattan and Prescott (2009) and Corrado et al. (2006) argue that the BEA data may under-estimate the extent of intangible investments and hence we regard our discrepancy as potentially data-driven.

In the second portion of this table, we focus on moments that are specific to government capital. The model delivers an investment-to-output average ratio that is on average slightly higher than in the data but statistically plausible. As a byproduct of this outcome, the share of government capital to total capital is sightly higher than in the data. In terms of volatility of $I_g/Y$, the model produces results consistent with our empirical confidence intervals. We find this outcome reassuring as it suggests that our framework is broadly reliable.

Thanks to the fact that government capital provides insurance against volatility shocks, its implied market value is substantial and predicted to be approximately 102% of total output. As it can be observed in the bottom portion of this table, private tangible capital is very risky and requires a levered premium of 6.3%, whereas government capital is overall as safe as a risk-free bond. This result is driven by the interplay of reallocation motives and riskiness of the present value of the monopolistic rents. We also notice that our model reproduces a substantial share of the $HML-R&D$ premium observed in the data. This result obtains because the present value of patent rents is very sensitive to volatility shocks.
Fig. 11. Impulse Responses to a Volatility Shock (I). This figure shows the response of detrended private consumption and investment to volatility shocks. All results are based on the VAR specified in equations (1) and (8), in which we measure uncertainty by productivity volatility estimated as in equations (3)–(7). The panels on the left (right) are based on quarterly (annual) data. Our sources are detailed in Appendix A. Our sample starts in 1969 and ends in 2011. Confidence intervals are adjusted for heteroscedasticity. The entries from our quarterly model are time-aggregated to an annual frequency in the panels on the right side.

Impulse Responses. To better compare our model to the data, in figures 11 and 12 we compare the VAR and the model impulse responses to an adverse volatility shock.

The reallocation toward government capital is broadly consistent with both quarterly and annual data. When we focus on government-to-total investment at a quarterly frequency, our model predicts an excessive reaction. Since the mean reversion in the model is stronger than in the data, time-aggregating our simulated data to annual frequency produces a smoother response.
In figure 12, we depict the response of both output growth and private R&D investment to an adverse volatility shock. Our setting predicts a strong immediate decline of R&D investment that is excessive compared to that observed in the data. At the same time, however, our model predicts a mean reversion that is much quicker than in the data. Given this limitation, it is not surprising that our model produces a milder decline in output growth than that predicted by our empirical VAR.

On the positive side, we note that the model prediction is within the VAR confidence intervals for about 8 quarters and that when we run the following regression in simulated data
\[ \frac{\Delta z_{t,t+g}}{10} = \mu + b_g k_{g,t} + k_{tot,t} + resid_t, \]
we obtain an estimate of \(-0.12\). According to the second column of table 5, this result, although milder in the data, belongs to our confidence interval and suggests that our framework can provide a reasonable explanation of the patterns in the data.

5 Sensitivity Analysis.

Preference shock. We depict the impulse responses of our model with preference shocks ($\phi_v = -0.015$) in the appendix, figure C3. In this extended model, the preference shock enhances our results as it promotes a stronger and prolonged response upon the arrival of the uncertainty shock. As a result, this extension helps us to better explain the growth slowdown observed in the data. These considerations are consistent with the quantitative results reported in table 7., column ‘PS’.

CRRA preferences. We depict the impulse responses of our model with CRRA in figure C4. The figure on the left shows that our results are not just driven by risk-aversion. Having an IES greater than one is important to replicate key features
This figure shows the response of detrended aggregate output and private output to volatility shocks. All results are based on the VAR specified in equations (1) and (8), in which we measure uncertainty by productivity volatility estimated as in equations (3)–(7). The panels on the left (right) are based on quarterly (annual) data. Our sources are detailed in Appendix A. Our sample starts in 1969 and ends in 2011. Confidence intervals are adjusted for heteroscedasticity. The entries from our quarterly model are time-aggregated to an annual frequency in the panels on the right side.

Indeed, when the agents have CRRA preference with high risk aversion and low IES, the model cannot explain the fall in private investment due to high uncertainty. Further, this calibration predicts that private tangible capital should be a good hedge against uncertainty shocks because it predicts an increase in the value of private capital stocks. Given our empirical investigation, this is a counterfactual result.

The panels on the right hand side of figure C4 show another important tension. If we set the IES to 2 and adopt CRRA preferences, the model output resembles the case in which there are no volatility shocks. The reason is that with a relative risk aversion of 1/2, the concerns for risk are basically null. These considerations explain why the moments produced under CRRA preferences deteriorate compared to those of the benchmark model (see table 7).
The role of government capital. If we assume that there is complete bias toward the private goods, we can compare our economy with one where government capital is null. To assure the existence of a solution we set $\chi = 0.0973$ so that the growth rate of the economy stays at 1.9%. Let $WC$ be the welfare cost of uncertainty in life-time consumption units. In our model, $WC$ can be computed as follows:

$$WC := \log \frac{U^{dss}}{A} - \log \frac{U^{sss}}{A}$$

where $U/A^{dss}$ ($U/A^{sss}$) is the utility ratio computed at the deterministic (stochastic) steady state.

When we compare $WC$ with and without government capital, we find a difference of 4%. Since we are keeping the average growth fixed at 1.9%, we interpret this result as suggesting that the pure uncertainty-induced reallocation of resources toward government capital improves welfare by 4%. This number suggests that the benefits of the pure hedging attainable through government capital are valuable but limited.

6 Conclusions

We propose a novel way to think about economic slow downs associated to high-uncertainty periods. Specifically, focusing on U.S. data we show the existence of a significant positive link between uncertainty and investment reallocation away from innovation-oriented stocks. Furthermore, we show that uncertainty spikes are associated to a reallocation from private to government capital. Our empirical tests suggest that this reallocation is a leading indicator of sluggish growth.

We rationalize these novel empirical findings in a production economy in which (a) the representative agent has an explicit fear toward uncertainty; and (b) in pe-
periods of high uncertainty, the agent exercises the option to devote more resources to government capital.

In normal times, investing in government capital is costly because government services are less valuable than the private ones. During periods of high uncertainty, in contrast, private capital is perceived as extremely risky, as the private sector has monopoly power and the present value of monopoly rents is highly exposed to uncertainty shocks. The resulting reallocation of resources toward government capital generates a temporary decline in private activity broadly consistent with the data.

Future work should focus on the interplay between government investment and distortionary taxation. Furthermore, since government capital is related to uncertainty, it should be used to explain the cross-section of equity returns.
References


Appendix A: Data Description

NIPA. The national income and product accounts (NIPAs) are a set of economic accounts produced by the Bureau of Economic Analysis (BEA). See Bureau of Economic Analysis (2014) for more underlying details on the construction of the data series.

Government Investment \( (I_g) \). Data are from the NIPA table 3.1. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q2. Government gross investment consists of spending by both general government and government enterprises for fixed assets that benefit the public or that assist government agencies in their productive activities. Put another way, government gross investment is a measure of the additions to, and replacements of, the stock of government-owned fixed assets. It consists of investment by both general government and government enterprises in structures (such as highways and schools), in equipment (such as military hardware), and in intellectual property products (software and research and development), and it includes own-account investment by government. See Bureau of Economic Analysis (2014) for more details.

Private Investment \( (I_p) \). Fixed private investment data are from the NIPA table 1.1.5. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q2. See Bureau of Economic Analysis (2014) for more details.

Government Capital \( (K_g) \) and Private Capital \( (K_p) \). Capital stock data are from the NIPA table 5.10. The annual data series begins in 1951 and our downloaded sample ends in 2013. We specifically use the data series for fixed assets (structures, equipment, and intellectual property products) and thus our total capital stock \( (K_g + K_p) \) does not include inventories. Capital stocks are accumulated totals computed
from gross investment, consumption of fixed capital, and other adjustments. See
Bureau of Economic Analysis (2014) for more details.

**Personal Consumption Expenditures** (*C*). Data are from the NIPA table 1.1.5. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q3. The annual data series begins in 1929 and our downloaded sample ends in 2014.

**Government Expenditures and Investment** (*G*). Data are from the NIPA table 1.1.5. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q3. The annual data series begins in 1929 and our downloaded sample ends in 2014. Compared to government investment, this data series also includes government expenditures.

**Gross Domestic Product** (*Y*). Data are from the NIPA table 1.1.5. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q3. The annual data series begins in 1929 and our downloaded sample ends in 2014.

**Total Factor Productivity Growth** (*Δa*). Business sector TFP data are from the Federal Reserve Bank of San Francisco. The quarterly data series begins in 1947:Q2 and our downloaded sample ends in 2015:Q2.

**Integrated Volatility.** We compute our quarterly integrated volatility measure as \(\sqrt{66 \times \frac{1}{N} \sum_{i=1}^{N} (r_{m,i} - r_{f,i})^2}\) where *N* is the number of daily observations in a given quarter and \(r_{m,i} - r_{f,i}\) is the market excess return for a given day. The resulting quarterly series spans 1926:Q3 to 2014:Q3. Market excess return data were downloaded from the Kenneth R. French Data Library.

**Real Personal Consumption Expenditures.** Data are from NIPA table 1.1.6. Units are billions of chained 2009 dollars. The quarterly data are seasonally adjusted. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in

Real Private Investment. Data are from the NIPA table 1.1.6. Units are billions of chained 2009 dollars. The quarterly data are seasonally adjusted. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q3. The annual data series begins in 1929 and our downloaded sample ends in 2014. so we use the total gross investment series, which includes both fixed and inventory investment. The fixed investment series, directly comparable to $I_p$, is only available from 1999.

Real Government Investment. Data are from the NIPA table 3.9.1. Units are percent change from the previous period. The quarterly data are seasonally adjusted. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q3. The annual data series begins in 1929 and our downloaded sample ends in 2014. Neither data series in chained 2009 dollars is available prior to 1999, so we use these percent change data series to construct the series of levels.

Growth Rates for Real Private Investment and Real Government Investment. We compute annual real growth rates using constructed real investment series. The only real investment series available from the BEA with data back to 1929 is for total (i.e. the sum of fixed and inventory) private investment. We convert the annual series for nominal private fixed investment and nominal government investment, which both start in 1929, to real figures using the implied deflator between nominal and real total private investment.

Price-Dividend Ratio. Price and dividend data are from Robert Shiller’s website (http://www.econ.yale.edu/~shiller/data.htm). These monthly data series begin in 1871:M1 and our downloaded sample ends in 2014:M6. We compute a quarterly price-dividend ratio data series by dividing the third month’s price by the sum
of dividends in each quarter. See the website for more details on the underlying data construction.

**Treasury Zero-Coupon Yields.** Data are from the Federal Reserve website ([http://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html](http://www.federalreserve.gov/pubs/feds/2006/200628/200628abs.html)). We aggregate the raw daily data to a quarterly frequency by taking the average within each quarter. The resulting quarterly data series begins in 1961:Q2 and our downloaded sample ends in 2015:Q1. See Gurkaynak et al. (2007) for details on the computation of the underlying daily data series.

**Inflation.** Data are from Ibbotson Associates. The monthly data begins in 1926:M1 and our downloaded sample ends in 2013:M12. We compound the monthly figures in each quarter to create a quarterly series.

**Private Research and Development (R&D) Investment.** Data are from the NIPA table 1.5.5. Units are billions of dollars. The quarterly data are seasonally adjusted. The quarterly data series begins in 1947:Q1 and our downloaded sample ends in 2015:Q3. The annual data series begins in 1929 and our downloaded sample ends in 2014.

**Real Private Research and Development (R&D) Investment.** The nominal series values are converted to real values using the implied deflator between the reported nominal and real private investment.

**Moody’s Seasoned Aaa/Baa Corporate Bond Yield Spreads.** Data are from Federal Reserve Bank of St. Louis Economic Database (FRED). The spreads are computed relative to the 10-year Treasury Constant Maturity. The monthly data series begin in 1953:M4 and our downloaded sample ends in 2016:M9. The quarterly data series are computed as the quarterly averages of the monthly series.

**Chicago Fed National Financial Conditions Index (NFCl) and Adjusted National Financial Conditions Index (ANFCI).** Data are from Federal Reserve

The NFCI is a weighted average of a large number of variables (105 measures of financial activity) each expressed relative to their sample averages and scaled by their sample standard deviations. The ANFCI removes the variation in the individual indicators attributable to economic activity and inflation before computing the index. The weekly data series begin on January 5, 1973 and our downloaded sample ends on February 10, 2017. The quarterly data series are computed as the quarterly averages of the weekly series.
Appendix B: Additional Empirical Results

Fig. B1. Response of Government Investment Share (integrated volatility). See note for Fig. 4(a). The only difference is that the sample starts in 1947.
**Fig. B2. Government R&D Intensity.** For COMPUSTAT firms, R&D intensity is R&D expense divided by total assets. Only firms with non-missing R&D expense are used in the quintile computations. For the government, we divide aggregate Government Gross Investment in R&D by total government capital stock. In panel (a), we show private R&D-intensity quintiles and government R&D intensity. In panel (b), we show shares of aggregate investment.
Appendix C: Additional Figures

Fig. C3. Impulse Responses. This figure shows percentage deviations from steady state. Our benchmark calibration is reported in table 6. The dashed line refers to the model with no preference shock ($\phi_v = 0$).
Fig. C4. Impulse Responses with CRRA. This figure shows percentage deviations from steady state. Our benchmark calibration is reported in table 6. The dashed line refers to the model with CRRA preferences and no preference shock.