BANCA D'ITALIA
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Temi di Discussione

(Working Papers)

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ISSN 1594-7939 (print)
ISSN 2281-3950 (online)

Printed by the Printing and Publishing Division of the Bank of Italy

SECULAR STAGNATION, R&D, PUBLIC INVESTMENT AND MONETARY POLICY: A GLOBAL-MODEL PERSPECTIVE

by Pietro Cova*, Patrizio Pagano[§], Alessandro Notarpietro* and Massimiliano Pisani*

Abstract

We evaluate the global macroeconomic effects of fiscal and monetary policy measures to counterbalance secular stagnation by simulating a five-region New Keynesian model of the world economy, calibrated to the United States (US), the euro area (EA), Japan (JP), China (CH), and the rest of the world (RW). The model includes investment in research and development (R&D) as a factor that affects global growth. Our main findings are as follows. First, a negative efficiency shock to R&D in the main advanced economies partially replicates the observed slowdown in long-term global growth and the decrease in interest rates. Second, in the medium- and long-term, the increase in US public investment favours global growth; in the short-term, it stimulates US economic activity but reduces foreign activity. Third, in the US an accommodative monetary stance, which provokes the crowding-in effect, amplifies the short-term macroeconomic effectiveness of public investment, without inducing additional negative spillovers. Fourth, EA, JP, and CH, by simultaneously increasing public investment and adopting an accommodative monetary policy, counterbalance US short-run negative spillovers and further enhance long-term world growth.

JEL Classification: E43; E44; E52; E58
Keywords: DSGE models, secular stagnation, open-economy macroeconomics, public investment, monetary policy.

Contents

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§ World Bank.

...there is much we can still do to reverse the aggregate productivity slowdown and dispel pessimism about our future.
Mario Draghi, President of the ECB.[1]

1 Introduction[2]

The relatively slow recovery of the U.S. (US) economy from the recent financial crisis has resurrected interest in Hansen's secular stagnation hypothesis, i.e, the industrialized economies show an increasing propensity to save and a decreasing propensity to invest, which result in excess savings and a depressed demand, determining low economic growth, inflation and interest rates.[3]

This view has been brought back to center stage by Summers (2013, 2014, 2015a and 2015b), who has emphasized one version of the hypothesis, based on the ageing of population (which has increased propensity to save) and the decline in the relative price of capital goods induced by technological innovation (which, despite having resulted in a substitution of capital for labour, may have lowered investment expenditure in nominal terms).[4]

A second version of the hypothesis, put forward notably by Gordon (2015), focuses on the supply side and in particular on the rate of growth of productivity, i.e., the economy's potential output for a given amount of available human and material resources employed in the production process. The key argument is that the great inventions that have resulted in massive productivity increases have for the most part already been introduced, so that a return to more moderate growth rates is inevitable.

The secular stagnation phenomenon is not confined to the US economy. Figures

[1]Draghi (2017).

[2]We thank for useful suggestions an anonymous referee, Nicholas Bloom, Ines Buono, and participants at the Banca d'Italia internal workshop on "Secular Stagnation and Financial Cycles" (March 2017), the University of Milan–Polytechnic University of Marche Conference on "Finance and Economic Growth in the Aftermath of the Crisis" (September 2017), the Annual Meeting of the Italian Economic Association (October 2017). The views expressed in this paper are those of the authors alone and should not be attributed to the Bank of Italy, the Eurosystem or the World Bank. Any remaining errors are the sole responsibility of the authors.

[3]See Hansen (1939).

[4]See also Eichengreen (2015).

1 and 2 report US and euro-area (EA) GDP growth and interest rates over the past four decades, respectively. Both variables clearly display a downward trend. As emphasized by Eggertsson et al. (2016), the average long-term interest rates all over the industrial world are now lower than they were a few years ago, in the immediate aftermath of the crisis, and financial markets suggest that inflation and real interest rates are expected to persistently remain at rather low levels not only in the US but also in Europe and Japan (JP). Therefore, it is relevant to appraise the secular stagnation hypothesis and explore its main policy implications in a global context.

Several policy measures have been suggested to exit from the secular stagnation. Among them is an increase in public infrastructure investment in the US and other main industrialized countries. By stimulating aggregate demand and favoring capital accumulation, possibly in conjunction with an accommodative monetary policy stance, it would help offset the global excess savings with respect to investment and support long-run growth.

We take this "global" approach and evaluate the impact of an increase in public infrastructure investment in the main advanced economies on global growth by simulating a dynamic general equilibrium model. The main contribution of the paper is to fully endogenize long-run growth in a large-scale multi-country New-Keynesian model via R&D accumulation. This allows us to evaluate the effects on both short- and long-run growth of increasing public infrastructure investment. Moreover, we assess the short-run effects of the fiscal expansion under alternative stances of monetary policy.

In the model, the world economy is composed of five blocs, calibrated to the EA, US, China (CH), JP, and the residual "rest of the world" region (RW). Crucially, the model features public infrastructure investment in each region and endogenous accumulation of research and development (R&D) in the tradable sectors of US, EA, JP, and CH (the main global investors in R&D in the data).

Public infrastructure investment is accumulated into public capital, which affects both the demand and the supply sides of the domestic economy. Each region is specialized in the production of final nontradable goods for consumption and investment purposes, and of intermediate tradable and nontradable goods. Both intermediate goods are produced according to a sector-specific Cobb-Douglas technology, that uses private capital, labor (both supplied by domestic households), and public capital. The latter is supplied by the domestic government, financed by raising public debt and lump-sum (non-distortionary) taxes and taken as given by firms when maximizing their profits.

The labor input is affected by a global technology trend, whose growth rate positively depends on the pace of global R&D accumulation. The latter feature is a (rather) novel one for models of this type, and it affects the growth rate of the world economy both in the short and long run (i.e., the world economy follows a long-run balanced growth path, driven by the growth rate of global labor-augmenting technology). R&D is supplied by domestic households, that accumulate it over time and optimally choose the amount of investment. Firms in US, EA, JP, and CH intermediate tradable sectors optimally demand R&D in the domestic perfectly competitive market.

Other features of the model are standard. In each country there are households that maximize utility with respect to consumption and leisure, and firms that maximize profits. Moreover, there are a Taylor-type monetary policy rule, nominal price and wage rigidities, real rigidities (habit in consumption and adjustment costs on investment), and a number of sources of real exchange rate fluctuations, i.e., home bias, local currency pricing, and intermediate nontradable goods.[5] International financial markets are incomplete, as only a riskless one-period bond, denominated in US dollars, is internationally traded.

The increase in public investment indirectly affects long-run global growth. The higher public capital accumulation makes inputs provided by the private sector, i.e., capital, labor, and R&D, more productive. Thus, firms have an incentive to increase their demand for those inputs, in particular for R&D. The increase in R&D favors the labor-augmenting technological progress and, thus, the long-run (steady-state) growth rate. Moreover, along the long-run balanced growth path of the model there is a single global (natural) interest rate, which holds in all regions and is proportional to the (long-run) growth rate of the economy.

We simulate the following scenarios. Initially, we design a secular stagna-

[5]The monetary policy stance does not affect results in the long run because nominal prices become fully flexible and money neutrality is verified (nominal rigidities hold only in the short run).

tion scenario (first scenario), in which, consistent with a supply-side approach to secular stagnation, the long-run growth rate of the labor-augmenting technology permanently decreases because of a negative shock to the global R&D investment efficiency, i.e., to the capability of converting investment into the (accumulated) stock of R&D. The size of the shock is such that the efficiency of R&D investment is permanently reduced to 90% of its initial level. The shock is in line with estimates provided by Bianchi et al. (2016). The persistent decline in R&D efficiency is documented by Bloom et al. (2017).

Starting from the new (long-run) steady state achieved through the previous simulation ("secular-stagnation steady state") we simulate a permanent increase in US public infrastructure investment by 1% of GDP under two alternative assumptions on the US monetary policy stance: (i) the US monetary authority follows the Taylor rule and, thus, allows for a gradual increase in the policy rate to counteract the expansionary effects of the increase in investment (second scenario); (ii) the authority announces to keep the policy rate constant at the initial steady-state level for two years, thus enacting forward guidance (FG) in the short run (third scenario). Two other scenarios are simulated. In one, public investment is permanently increased in US, EA, JP, and CH by 1% of GDP under a standard monetary policy stance (fourth scenario). In the other, the same increase in public investment occurs under a two-year FG in all the four regions (fifth scenario). The size of the public investment shock is of the same order of magnitude as the reduction in advanced economies' public investment observed in recent decades (see International Monetary Fund 2014).

Finally, we perform a sensitivity analysis. As the effects of the public investment shock are influenced by the relative weight of public capital in private firms' production and by the spillovers of R&D investment across countries, we analyze the sensitivity of the results of the fourth scenario to different calibrations of the corresponding relevant parameters.

All scenarios are simulated under perfect foresight, so that households and firms perfectly anticipate the future path R&D investment efficiency and policy measures.

Our main results are as follows. First, a negative efficiency shock to R&D in the main advanced countries partially replicates the observed slowdown in the long-run global growth and decrease in interest rates. Second, in the medium and long run the increase in US public investment favors global economic growth; in the short run, it stimulates US economic activity but reduces foreign activity. Third, in the US an accommodative monetary stance, by crowding-in private consumption and investment, amplifies the short-run macroeconomic effectiveness of public investment, without inducing additional negative global spillovers. Fourth, EA, JP, and CH, by simultaneously increasing public investment and adopting an accommodative monetary policy, counterbalance the US short-run negative spillovers and further enhance long-run world economic growth. Finally, results are robust to alternative calibrations of key R&D-related parameters.

Overall, our results clearly speak in favor of coordinating global expansions in public investment.

Some recent contributions have provided a formal treatment of the secular stagnation hypothesis within a dynamic general equilibrium framework. Benigno and Fornaro (2015) build a New Keynesian closed-economy model where pessimistic expectations can permanently reduce productivity growth. Bianchi et al. (2016) build and estimate a dynamic general equilibrium model with endogenous technological progress, where total factor productivity is endogenous and related to R&D and technology adoption rates. Eggertsson et al. (2017) build a closed-economy, overlapping generation model where the zero lower bound is chronically binding. They focus on the role of population growth in reducing equilbrium interest rates. We build on the formalization of R&D as in Bianchi et al. (2016). Different from the above-mentioned contributions, we fully endogenize long-run growth in a large-scale multi-country New-Keynesian model via R&D accumulation.

The paper is organized as follows. Section 2 briefly describes the model, its equilibrium, and the calibration. Section 3 describes the simulated scenarios. Section 4 reports the results. Section 5 concludes.

2 The model

We first provide an overview of the model. Subsequently, we illustrate the crucial features for the simulations. Finally, we report the calibration.

2.1 Overview

We build and simulate a five-region New Keynesian dynamic general equilibrium model of the world economy, calibrated to US, EA, JP, CH, and RW.[6] In each country households consume, invest in physical capital, R&D (in the case of US, EA, JP, and CH), riskless one-period bonds, and supply labor. One bond is denominated in domestic currency and is traded domestically; a US dollar-denominated bond also exists, that is traded internationally. The domestic-currency bond pays the monetary policy rate set by the domestic central bank. The internationally traded bond pays the US monetary policy rate. The related Euler equations imply that a forward-looking uncovered interest parity condition holds, linking the interest rate differential to the expected depreciation of the currency vis-à-vis the US dollar.[7]

Consumption and investment consist of final nontradable goods, which result from combining constant-elasticity-of-substitution (CES) bundles of intermediate tradable and nontradable goods. The former are domestically produced or imported. Households supply differentiated labor services to domestic firms and act as wage setters in monopolistically competitive labor markets by charging a mark-up over their marginal rate of substitution between consumption and leisure. Finally, households own domestic firms.

On the production side, there are perfectly competitive firms that produce final nontradable goods (consumption and investment goods) and monopolistic firms that produce intermediate goods. The final goods are sold domestically and are produced by combining all available intermediate goods, using a CES production function. The resulting bundles may have different composition.

The model has two rather novel features. First, it allows for public investment in infrastructure in each region. Second, following Bianchi et al. (2016), it allows for endogenous accumulation of R&D. Specifically, both intermediate tradable and nontradable goods are produced according to a sector-specific Cobb-Douglas tech-

[6] In each region, size refers to the overall population and to the number of firms operating in each sector. For details on the model equations, see Pesenti (2008) and appendix in Cova et al. (2016).

[7] We make the assumption of a cashless economy, thus we do not consider utility maximization with respect to money demand.

nology, that uses private capital, labor (both supplied by domestic households), and public capital (firms take the public capital stock as exogenously given when maximizing their profits). The labor input is subject to a global technological trend, which positively depends on the accumulated stock of (global) R&D. Firms in the US, EA, JP, and CH intermediate tradable sectors optimally demand R&D in the domestic perfectly competitive market. R&D is supplied by domestic households that accumulate it over time and optimally choose the amount of investment. Crucially, we assume the existence of an "efficiency" shock that affects the accumulation process of R&D.[8] Moreover, there are R&D spillovers to the other sectors and to other countries.

Finally, in each country there is a Taylor-type monetary policy rule. We also include adjustment costs on real and nominal variables, ensuring that consumption, production, and prices react in a gradual way to a shock. On the real side, habits and quadratic costs delay the adjustment of households consumption and investment (in private capital and in R&D), respectively. On the nominal side, quadratic costs make wages and prices sticky.[9]

In what follows we report the main equations associated with US R&D accumulation, public investment and monetary policy. Similar equations hold in the other regions but RW, which by assumption does not invest in R&D.

2.2 Firms' production function

The production function of the generic firm f^{US} in the US intermediate tradable sector is

$$Y_{T,t}^{US}\left(f^{US}\right)=\left(K_{T,t}^{US,P}\left(f^{US}\right)\right)^{\alpha_{1T}}\left(TREND_{t}^{US}\left(f\right)L_{T,t}^{US}\left(f^{US}\right)\right)^{\alpha_{2T}}\left(K_{t-1}^{US,G}\right)^{1-\alpha_{1T}-\alpha_{2T}}, \tag{1}$$

where $K_{T,t}^{US,P}\left(f^{US}\right)$ is the demand for private capital, $K_{t-1}^{US,G}$ the public capital, and $L_{T,t}^{US}\left(f^{US}\right)$ the demand for labor. The parameters $0<\alpha_{1T},\alpha_{2T}<1$, $\alpha_{1T}+\alpha_{2T}<1$, are the weights on private capital and labor, respectively. The labor-augmenting technology shock specific to the generic US firm f, $TREND^{US}\left(f^{US}\right)$, is defined as

[8] See Anzoategui et al. (2016).

[9] See Rotemberg (1982).

$$TREND_t^{US}\left(f^{US}\right) = \left(\left(R\&D_t^{US}\left(f^{US}\right)\right)^{\eta^{US}}\left(R\&D_t^{US}\right)^{1-\eta^{US}}\right)^{\gamma^{US}} \times \quad (2)$$
$$\left(R\&D_t^{EA}\right)^{\gamma^{EA}} \times \left(R\&D_t^{JP}\right)^{\gamma^{JP}} \times \left(R\&D_t^{CH}\right)^{1-\gamma^{US}-\gamma^{EA}-\gamma^{JP}}, \forall f^{US},$$

where $R\&D^{US}\left(f^{US}\right)$ is the US firm f^{US}'s demand for the stock of $R\&D$ (accumulated by domestic households), while the aggregate stock of $R\&D$ in the US, EA, JP, and CH are respectively

$$R\&D^{US} = \int_0^{n^{US}} R\&D_t^{US}\left(f^{US}\right) df^{US} \quad (3)$$
$$R\&D^{EA} = \int_{n^{US}}^{n^{US}+n^{EA}} R\&D_t^{EA}\left(f^{EA}\right) df^{EA} \quad (4)$$
$$R\&D^{JP} = \int_{n^{US}+n^{EA}}^{n^{US}+n^{EA}+n^{JP}} R\&D_t^{JP}\left(f^{JP}\right) df^{JP} \quad (5)$$
$$R\&D^{CH} = \int_{n^{US}+n^{EA}+n^{JP}}^{n^{US}+n^{EA}+n^{JP}+n^{CH}} R\&D_t^{CH}\left(f^{CH}\right) df^{CH} \quad (6)$$
$$(7)$$

where $0 < n^{US}, < n^{EA}, < n^{JP}, < n^{CH} < 1$ is the number of firms in the US, EA, JP, and CH tradable sectors, respectively, 1 is the size of the world economy and $n^{US} + n^{EA} + n^{JP} + n^{CH} < 1$.

The $TREND^{US}\left(f^{US}\right)$ is positively affected by the stock of R&D optimally chosen by the generic firms f in the US, EA, JP, and CH intermediate tradable sectors. When choosing the optimal $R\&D\,(f)$, the generic firm f^{US} takes into account its direct contribution to $TREND^{US}\left(f^{US}\right)$ (measured by the parameter η, $0 < \eta < 1$). The parameters $\gamma's$ measure the elasticity of $TREND^{US}\,(f)$ with respect to country-specific R&D ($0 < \gamma^{US}, \gamma^{EA}, \gamma^{JP} < 1$, $\gamma^{US} + \gamma^{EA} + \gamma^{JP} < 1$).

The generic US firm f optimally demands capital, labor, and R&D (all of them are supplied by domestic households), taking as given prices, the stock of public capital (accumulated by domestic government), the R&D accumulated by other (domestic and foreign) individual firms, and the aggregate R&D in each domestic and foreign sector.[10]

A similar trend holds for every firm in EA, JP, and CH, and RW, respectively

$$\begin{array}{rcl} TREND_t^{EA}\left(f^{EA}\right) & = & \left(\left(R\&D_t^{EA}\left(f^{EA}\right)\right)^{\eta^{EA}}\left(R\&D_t^{EA}\right)^{1-\eta^{EA}}\right)^{\gamma^{EA}} \times \\ & & \left(R\&D_t^{US}\right)^{\gamma^{US}} \times \left(R\&D_t^{JP}\right)^{\gamma^{JP}} \times \left(R\&D_t^{CH}\right)^{1-\gamma^{US}-\gamma^{EA}-\gamma^{JP}}, \\ TREND_t^{JP}\left(f^{JP}\right) & = & \left(\left(R\&D_t^{JP}\left(f^{JP}\right)\right)^{\eta^{JP}}\left(R\&D_t^{JP}\right)^{1-\eta^{JP}}\right)^{\gamma^{JP}} \times \\ & & \left(R\&D_t^{US}\right)^{\gamma^{US}} \times \left(R\&D_t^{EA}\right)^{\gamma^{EA}} \times \left(R\&D_t^{CH}\right)^{1-\gamma^{US}-\gamma^{EA}-\gamma^{JP}}, \\ TREND_t^{CH}\left(f^{CH}\right) & = & \left(\left(R\&D_t^{CH}\left(f^{CH}\right)\right)^{\eta^{CH}}\left(R\&D_t^{CH}\right)^{1-\eta^{CH}}\right)^{1-\gamma^{US}-\gamma^{EA}-\gamma^{JP}} \times \\ & & \left(R\&D_t^{US}\right)^{\gamma^{US}} \times \left(R\&D_t^{EA}\right)^{\gamma^{EA}} \times \left(R\&D_t^{JP}\right)^{\gamma^{JP}}, \\ TREND_t^{RW}\left(f^{RW}\right) & = & \left(R\&D_t^{CH}\right)^{1-\gamma^{US}-\gamma^{EA}-\gamma^{JP}} \times \\ & & \times \left(R\&D_t^{US}\right)^{\gamma^{US}} \times \left(R\&D_t^{EA}\right)^{\gamma^{EA}} \times \left(R\&D_t^{JP}\right)^{\gamma^{JP}}. \end{array} \quad (8)$$

As we consider a symmetric equilibrium, in which all firms belonging to the same sector make the same choices, $TREND_t^{US}\left(f^{US}\right)$ will end up being the same for every US firm. The same is true for every firm in EA, JP, and CH. Thus, $TREND_t^{US}\left(f^{US}\right)$ will be equal to all trends in other regions. This implies that there is a (common) global trend of labor-augmenting technology shock $TREND_t^{world}$ (i.e., in the symmetric equilibrium the trend is common across all firms producing intermediate tradable and nontradable goods in all regions of the global economy, $TREND_t^{US}$=$TREND_t^{EA}$=$TREND_t^{JP}$=$TREND_t^{CH}$=$TREND_t^{RW}$ =$TREND_t^{world}$).

Firms in the nontradable sector demand physical capital and labor supplied by domestic households, and take public capital and the (global common) labor-augmenting technology as given (they do not invest in R&D).

[10] Firms do not demand public capital and there is no price or tariff paid for its use.

2.3 R&D accumulation, long-run growth and interest rate

Following Bianchi et al. (2016), the US R&D is accumulated by the generic US household i according to

$$R\&D_t(i) = (1-\delta_{R\&D}) R\&D_{t-1}(i) + Z_{I_{R\&D,t}} \left(1 - \frac{\psi_{R\&D}}{2}\left(\frac{I_{R\&D,t}}{I_{R\&D,t-1}} - gr_t\right)\right)^2 I_{R\&D,t}(i), \tag{9}$$

where we have dropped the "US" superscript for simplicity. The parameter $0 < \delta_{R\&D} < 1$ is the depreciation rate; $\psi_{R\&D} > 0$ is a parameter measuring investment adjustment costs; $I_{R\&D,t}$ is the investment in $R\&D$ (whose composition is assumed to be the same as that of private consumption); $Z_{I_{R\&D,t}}$ represents the shock to the marginal efficiency of R&D investment, and gr_t is the gross growth rate of the global labor-augmenting technology trend,

$$gr_t \equiv \frac{TREND_t^{world}}{TREND_{t-1}^{world}}. \tag{10}$$

Finally, along the long-run balanced growth path the global real (natural) interest rate RR is pinned down by the growth rate gr, endogenously determined by R&D investment, and the households' subjective discount factor $< \beta < 1$,

$$RR = \frac{gr}{\beta}. \tag{11}$$

2.4 Public capital

The US fiscal authority exogenously decides the amount of investment in infrastructure and, thus, the accumulation of public capital, $K_{G,t}$, according to

$$K_{G,t} = (1-\delta_G) K_{G,t-1} + I_{G,t}, \tag{12}$$

where $0 < \delta_G < 1$ is the depreciation rate, and $I_{G,t}$ is public investment.[11]

[11] We do not explicitly consider the possibility that public investment takes time to accumulate into physical capital. For the public capital projects with delay between the authorization of a government spending plan and the completion of an investment project, see Kydland and Prescott (1982) and Leeper et al. (2010).

The government budget constraint is

$$B_{G,t} - B_{G,t-1}R_{t-1} \leq P_{N,t}C_{G,t} + P_t I_{G,t} - TAX_t, \tag{13}$$

where $B_{G,t} > 0$ is public debt, which is financed by a one-period nominal bond issued in the domestic bond market, paying the (gross) monetary policy interest rate R_t. The variable $C_{G,t}$ represents government purchases of goods and services, while $TAX_t > 0$ (< 0) are lump-sum taxes (transfers) to households. Consistent with the empirical evidence, $C_{G,t}$ is fully biased towards the nontradable intermediate good. Therefore, it is multiplied by the corresponding price index $P_{N,t}$.[12] Investment in public capital $I_{G,t}$ is assumed to have the same composition as private consumption, in line with the existing literature. Thus, it is pre-multiplied by the consumption price deflator P_t.

The government follows a fiscal rule defined on lump-sum taxes to bring the public debt as a % of domestic GDP, $b_G > 0$, in line with its long-run (steady-state) target $\bar{b}_G$ and to stabilize its rate of change.[13]

The rule is

$$\frac{TAX_t}{TAX_{t-1}} = \left(\frac{b_{G,t}}{\bar{b}_G}\right)^{\phi_1} \left(\frac{b_{G,t}}{b_{G,t-1}}\right)^{\phi_2}, \tag{15}$$

where parameters ϕ_1, ϕ_2 are greater than zero, calling for a increase (reduction) in lump-sum taxes whenever the current-period public debt (as a ratio to GDP) is above (below) the target and the previous-period public debt, respectively. We choose lump-sum taxes to stabilize public finance as they are non-distortionary and, thus, allow for a "clean" evaluation of the macroeconomic effects of public investment.

[12] See Corsetti and Mueller (2006).

[13] The definition of nominal GDP is

$$GDP_t = P_t C_t + P_t^I I_t + P_t I_{R\&D,t} + P_t I_{G,t} + P_{N,t} C_{G,t} + P_t^{EXP} EXP_t - P_t^{IMP} IMP_t, \tag{14}$$

where P_t, is the price of private consumption, public investment, and investment in R&D, given that we assume that public investment and R&D investment bundles have the same composition as private consumption. P_t^I, $P_{N,t}$, P_t^{EXP}, P_t^{IMP} are prices of private investment in physical capital, public consumption, exports, and imports, respectively.

2.5 Monetary authority

In each country the monetary authority sets the policy rate R_t according to a Taylor rule of the form

$$\left(\frac{R_t}{\bar{R}}\right)^4 = \left(\frac{R_{t-1}}{\bar{R}}\right)^{4\rho_R} \left(\frac{\Pi_{t,t-3}}{\bar{\Pi}^4}\right)^{(1-\rho_R)\rho_\pi} \left(\frac{GDP_t}{GDP_{t-1}}\frac{1}{gr_t}\right)^{(1-\rho_R)\rho_{GDP}}. \tag{16}$$

The parameter ρ_R $(0 < \rho_R < 1)$ captures the inertia in interest-rate setting, while the term $\bar{R}$ represents the steady-state gross nominal policy rate. The parameters ρ_π and ρ_{GDP} are respectively the weights of yearly CPI inflation rate $\Pi_{t,t-3} \equiv P_{C,t}/P_{C,t-4}$ (in deviation from the long-run steady-state target $\bar{\Pi}^4$) and the gross growth rate of the stationary (de-trended) component of GDP, which can be expressed as

$$\frac{GDP_t}{GDP_{t-1}}\frac{1}{gr_t} \equiv \frac{GDP_t/TREND_t^{world}}{GDP_{t-1}/TREND_{t-1}^{world}}. \tag{17}$$

In some scenarios the central bank is assumed to keep the policy rate constant at its (initial) steady-state level for two years (FG).

2.6 Equilibrium

In each country the initial asset positions, preferences, and budget constraints are the same for all households and for all firms belonging to the same sector. Moreover, profits from ownership of domestic monopolistically competitive firms are equally shared among households. Thus, in each country we have a representative household and a representative firm for each sector (final nontradables, intermediate tradables, and intermediate nontradables). The implied symmetric equilibrium is a sequence of allocations and prices such that, given initial conditions and shocks, households and firms satisfy their corresponding first order conditions, the monetary rules, fiscal rules, and government budget constraints hold, and all markets clear.

2.7 Calibration

Tables 1 to 5 report the (quarterly) calibration of the model parameters, which are set to match the empirical evidence on the pre-secular stagnation period (1970s-80s) and in line with the existing literature.

Table 1 shows the preference and technology parameters. Preferences are the same across households of different regions. The intertemporal elasticity of substitution is set equal to 1.0, the habit parameter to 0.6, and the Frisch elasticity to 0.50. We further assume a depreciation rate of physical and R&D capital to 0.025, consistently with an annual depreciation rate of 10%.

As to final goods, the degree of substitutability between domestic and imported tradables is higher than that between tradables and nontradables (2.5 vs 0.5).

Concerning the parameters related to R&D technology, we set the elasticity of $TREND^{world}$ to regional R&D investment, γ, to 0.30 in EA, 0.40 in US, 0.10 in CH and 0.20 in JP. The contribution of individual firms' R&D investment to $TREND^{world}$ (η) is set to 0.23 in the EA, 0.18 in the US, 0.42 in CH, and 0.35 in JP. These parameters are chosen so that the steady-state ratio of R&D investment to GDP matches aggregate data (see Table 5).

Table 2 reports real and nominal rigidities. For real rigidities, parameters of the adjustment costs on investment changes are set to 4.5 in all countries, both for investment in physical capital and for investment in R&D. For nominal rigidities, we set the adjustment costs for wages to 600; for prices of domestic tradable and nontradable goods, to 600; for prices of imported goods, to 6.00.[14]

Table 3 shows price and wage markup values. We identify the intermediate nontradable and tradable sectors in the model with the services and manufacturing sectors in the data, respectively. In each region the markup in the nontradable sector is assumed to be higher than that in the tradable sector and in the labor market, where it is assumed to be equal across sectors.[15]

[14]The value 600 for quadratic adjustment costs in prices is roughly equivalent to a four-quarter contract length under Calvo-style pricing, as highlighted, among others, by Faruquee et al. (2007). The value 6 for import price adjustment costs is consistent with a relatively quick pass-through of the nominal exchange rate into import prices.

[15]Our values are in line with other existing similar studies, such as Bayoumi et al. (2004), Faruqee et al. (2007), Everaert and Schule (2008). Many, if not all, of these studies refer to Jean and Nicoletti (2002) and Oliveira Martins and Scarpetta (1999) for estimates of markups.

Table 4 reports the parameters of the policy rules. For monetary policy rules, the interest rate reacts to the its lagged value (inertial component of the monetary policy), inflation and output growth (see equation 16). For fiscal policy, the parameters governing the speed of adjustment of public debt are assumed equal across countries. Specifically, we set $\phi_1 = 2.01$ and $\phi_2 = 10.01$ (see equation 15).

Table 5 shows the great ratios for the five regions. The weight of domestic tradable goods in the consumption and investment tradable baskets is different across countries, to match multilateral import-to-GDP ratios.

Table 6 reports the trade matrix. We then set the weights of bilateral imports to match it.[16] It is interesting to note that trade with the RW clearly dominates trade patterns for all the other regions.

The implied global growth rate is 2.7%, in line with the evidence reported in Figure 1 and the one provided by the Conference Board (2015) on the growth rate of global TFP.

Finally, we set the discount factor so that, given the steady-state growth rate of the wordwide, the (pre-shock) steady-state annualized real interest rate is 4.8%, in line with the evidence reported in Figure 2.

3 Simulated scenarios

We initially design a secular-stagnation scenario, in which the long-run growth rate of the labor-augmenting technology permanently decreases. Specifically, we simulate a negative shock, $Z_{I_{R\&D}}$, to the global R&D investment efficiency, i.e., to the capability of converting investment into (accumulated) stock of R&D (see equation 9). The size of the shock is such that the efficiency is permanently reduced to 90% of its initial level. The shock is in line with estimates provided by Bianchi et al. (2016). The persistent decline in R&D efficiency is documented, among others, by Bloom et al. (2017).

On top of the secular stagnation, i.e. starting from the new steady state characterized by lower growth and lower interest rates, we simulate a permanent increase

[16] We rely on the United Nations' Commodity Trade Statistics (COMTRADE) data on each region's imports of consumer and capital goods, to derive the matrix delineating the pattern and composition of trade for all regions' exports and imports.

in US public infrastructure investment by 1% of GDP under two alternative assumptions on the US monetary policy stance: (i) the US monetary authority follows the Taylor rule (see equation 16) and, thus, allows for a gradual increase in the policy rate to counteract the expansionary effects of the increase in investment (second scenario); (ii) alternatively it announces to keep the policy rate constant at the initial level for two years, thus enacting FG in the short run (third scenario). Two other scenarios are simulated. In one, public investment is permanently increased in US, EA, JP, and CH under a standard monetary policy stance (fourth scenario). In the other, the same increase in public investment occurs under a two-year FG in all the four regions (fifth scenario). The size of the public investment shock, equal to +1% of GDP, is of the same order of magnitude as the reduction in advanced economies' public investment observed in recent decades.[17] Finally, we perform a sensitivity analysis. As the effects of the public investment shock are influenced by the relative weight of public capital in private firms' production and by the spillovers of R&D investment across countries, we analyze the sensitivity of the results of the fourth scenario to variations in the corresponding relevant parameters.

All scenarios are simulated under perfect foresight, so households and firms perfectly anticipate the future path of R&D investment efficiency and policy measures.

4 Results

4.1 Secular stagnation

We first evaluate the macroeconomic effects of permanently reducing the growth rate of the global labor-augmenting technology shock.

Figures 3 and 4 present the responses of the main US macroeconomic variables to the negative shock to R&D accumulation.[18]

As reported in Figure 3, because of the lower R&D investment efficiency, US

[17]See International Monetary Fund (2014).

[18]In the charts we report the first 80 quarters to show long-run responses. Alternatively, 20 quarters are reported when the emphasis is on the short-run effects, typically when the accommodative monetary policy stance is considered.

firms decrease the growth rate of R&D investment relative to the before-shock long-run growth rate (i.e, the before-shock steady-state balanced growth path). Consistent with that, the global technology growth permanently decreases, implying that the nominal interest rate permanently declines as well. The decline is gradual, consistent with the inertial term in the monetary policy rule. There is an initial increase in the relative price of investment in (private) physical capital, because households substitute investment in physical capital (see below) for investment in less efficient R&D. The initial increase is followed by a permanent, mild decline.

The GDP growth initially undershoots its new lower long-run value, because prices are sticky in the short run and the economy adjusts mainly through changes in the quantities (see Figure 4). Inflation initially decreases and, thereafter, gradually returns to its initial baseline level. Similarly, all of GDP's components undershoot the long-run growth rate. Consumption growth sharply declines on impact, in line with the increase in the ex-ante real interest rate (not reported). The lower consumption growth makes resources available for higher investment in physical capital, whose growth rate initially increases and, after around eight quarters, decreases below the baseline. Exports growth initially increases, favored by the rise in investment in other countries (see below). Imports growth persistently decreases, consistent with the lower growth in the US aggregate demand. Hours worked initially decline, given the initial drop in labor-augmenting technology growth. Thereafter, they increase, in line with the (partial) recovery of the technology trend. The real wage permanently increases. In the short run it barely moves (because of nominal wage and price rigidities). In the long run it stabilizes at a new higher level, because firms augment their demand for labor, to compensate for labor productivity increasing at a slower pace.

Figure 5 depicts the responses of other regions' variables. In every region, the growth rate of GDP falls markedly in the short run. As in the case of the US, that decline is associated with a large decrease in consumption growth, which frees resources for investment growth; the latter increases in the short run to limit, via physical capital accumulation, the decrease in output growth. Hours worked initially decrease and thereafter increase, when the labor productivity is favored by the temporary larger stock of physical capital. Exports growth initially increases in the EA and JP, while it decreases in CH and RW. To the opposite, import growth increases in CH and RW, and decreases in EA and JP. Consistent with the paths of exports and imports, the EA and JP currencies appreciate in real terms vis-à-vis the US dollar less than the CH and RW currencies do. The mechanism behind the different depreciations reflects differences in R&D. Specifically, the negative R&D shock affects US, EA, JP more than CH, given the chosen calibration (R&D has a lower weight in CH production), while RW does not invest in R&D by assumption. Thus, GDP growth decreases by relatively more in the US, EA, and JP. This favors in the medium run a slightly larger decrease in their policy rates and, thus, the depreciation of their currencies vis-à-vis the CH and RW currencies, that benefits US, EA and JP exports. The reduction in the growth rates induces lower inflation in all regions. Finally, the relative price of investment decreases relatively more in CH and RW because of the appreciation of their exchange rates and the large import content of the investment bundles.

The slower R&D accumulation permanently reduces the growth of technology, which determines the long-run growth rate of the world economy. Thus, the latter converges to a new lower long-run balanced growth path, in which the annualized growth rate is 1.8% (from 2.7%, as reported in Table 7). The global interest rate decreases from 4.8% to 3.8%.

Overall, the negative shock to R&D allows us to replicate the main stylized facts associated with the secular stagnation hypothesis, i.e., the permanent slowdown in global economic activity and the permanent reduction in the global interest rate, in line with the evidence reported in Figures 1 and 2. The associated decline in the trend growth of global labor-augmenting technology matches the estimates by Conference Board (2015).

4.2 Increase in US public investment under alternative assumptions on the monetary policy stance

Figures 6 and 7 present the responses of the main US variables when the US fiscal authority permanently increases public investment by 1% of GDP starting from the secular-stagnation steady state (the new baseline), which the world economy achieved at the end of the previous simulation (i.e., after the negative shock to R&D

accumulation). Public investment in the other regions is instead kept constant at its baseline level. The figures report results obtained when the increase in US public investment is either accompanied by an immediate increase in the US monetary policy rate or, alternatively, by a 2-year FG.

The increase in the US public investment induces firms to increase R&D accumulation (see Figure 6). The effects are more pronounced in the case of 2-year FG, as the larger fall in the short-term real interest rate (not reported) fosters higher investment in R&D on impact. The latter favors a permanent increase in the labor-augmenting technology. In the long run the interest rate increases by approximately 0.2 percentage points.

The US economy benefits from the fiscal and monetary policy measures in the short run (see Figure 7). US GDP growth rate increases. The public deficit-to-GDP ratio initially increases, reflecting the increase in public expenditure. The public debt-to-GDP ratio increases more slowly. Both the deficit and the debt-to-GDP ratio return to their initial levels after about five years, as the fiscal rule (15) is always at work. Hence, there are no long-run variations in the debt-to-GDP ratio, since lump-sum taxes are adjusted to ensure that the target is met. In the case of a 2-year FG the larger expansionary effect on GDP implies an initial small decrease in the debt-to-GDP ratio, which subsequently increases above its initial level in the medium term.

Figures 8-11 report the spillovers on the EA, JP, CH, and RW economies, respectively. Compared to the initial secular stagnation steady state (baseline), the US spillovers are negative in the short run. Focusing, for example, on the EA (Figure 8), GDP growth decreases, because EA households lend to US households in order to finance the additional US growth rate induced by the increase in US public investment. Thus, both EA consumption and investment growth rates initially decrease, so that imports growth initally falls as well. The export growth rate increases, reflecting higher US aggregate demand.

In the case of "accommodative" US monetary policy (i.e. the 2-year FG), the euro appreciates in real terms vis-à-vis the US dollar, implying a slightly negative price-competitiveness effect on the EA tradable goods. However, in the medium run exports growth is (slightly) larger than in the case of standard monetary policy rate, because of the larger US aggregate demand.

Figures 9, 10, 11 show the macroeconomic effects on JP, CH, and RW variables, respectively. Results for JP and CH closely mimic those for the EA. One difference emerges when looking at the RW variables. RW import growth increases in the short run, as its currency appreciates in real terms against the currencies of the other regions. The exchange rate appreciation, by making imports cheaper, induces a positive wealth effect on RW households. Moreover, and different from other regions, the lack of R&D investment induces RW households to substitute consumption for investment growth and hours worked.

Overall, we find that in the short run the mix of permanent increase in US public investment and monetary policy accommodation can partially counterbalance the negative macroeconomic effects of secular stagnation on the world economy.

In the long run the global growth rate registers a larger value than in the (initial) secular-stagnation steady-state. Consistent with that, the global (and common across countries) interest rate increases. As reported in Table 7, the growth rate increases to 2% (from 1.8%), the interest rate to 4.1% (from 3.8%).

4.3 Simultaneous increase in US, EA, JP, and CH public investment

Figures 12-15 report the responses of the US, EA, RW variables when US, EA, JP, and CH simultaneously raise public investment by 1% of GDP.[19] RW public investment is instead constant at its baseline level.

Compared to the case in which the US is the only country to increase public investment (Figure 6) the increase in the global public investment induces firms to increase US R&D at a faster rate in the medium and long run (see Figure 12). Thus, there is a larger permanent increase in the labor-augmenting technology. In the long run the interest rate increases more. Instead, the relative price of private investment increases to a lower extent.

As reported in Figure 13, the US benefits from higher GDP growth in the long run, but it experiences a slower pace of GDP growth in the short run, compared to when it is the sole region to expand public infrastructure spending (compare

[19] Results for CH and JP are similar to those of the EA. They are not reported to save on space and are available upon request.

with Figure 7). The result is due to lower global savings available to finance the US expansion. Thus, the US economy relies now more on its own savings, which translates into a stronger fall in US consumption growth in the short run and a correspondingly lower inflation rate. The latter determines a smaller increase of the monetary policy rate in the short run. In the short run the US export growth increases by more than in the case of US-only expansion, favored by the increase in global demand, while US import growth increases by less, because of the lower increase in US aggregate demand. Both the public deficit and the public debt-to-GDP ratio increase to a smaller extent in the medium term, compared to the case of a US-only fiscal stimulus. Both variables are back to their initial levels after five years.

Compared to the case in which public investment increases only in the US, EA GDP growth now rises more in both the short and long run (compare Figure 14 with Figure 8).

In the short run the EA output growth benefits from the increase in global public investment; in the medium and long term, it benefits from the endogenous supply-side effects induced by the additional increase in global R&D, activated by the surge in public infrastructure. Thus, thanks to the fiscal stimulus, R&D accumulation increases not only in the US but also in EA (and in JP and CH, not reported). The EA now exports somewhat less and imports more. The import growth increases because of the increase in public investment. The figure also reports the results for the EA of simultaneously increasing EA, US, JP, and CH public investment under the assumption of 2-year FG. The EA short-run growth rate is magnified by the policy mix. There is less crowding-out of consumption and investment, that favors international trade. The dynamics of the deficit and debt-to-GDP ratios are qualitatively similar to those observed in the US.

In the RW net exports increase to finance the fiscal expansion in the other regions.

Finally, the stronger world aggregate demand also determines on average higher global interest rates both in the short (except for the RW) and in the long run, due to the stronger global growth rate induced by higher R&D accumulation.

As reported in Table 7, in the long run the global growth and interest rate increase to 2.3% and 4.4% from 1.8% and 3.8%, respectively.

Overall, the simultaneous cross-country increase in public investment favors global activity in both short and long run because of the positive effects on R&D. The short-run growth rate of the world economy can be further enhanced by a cross-country accommodative monetary policy stance that accompanies the fiscal stimulus. Our results confirm, as advocated by Summers (2016), that coordination is key for favoring an exit from secular stagnation. If the expansion is solely driven by one country, the US in our case, it will lead in the long run to higher global growth and interest rates, thanks to endogenous growth spillovers, but, in the short run, it will entail negative international spillovers.

4.4 Sensitivity analysis

The results illustrated in the previous section show that a coordinated increase in public investment can effectively increase long-run GDP growth and real interest rates, when advanced economies face a secular stagnation scenario. Those results clearly depend on three crucial parameters: (i) the weight of public capital in firms' production function $(1 - \alpha_{1T} - \alpha_{2T})$, (ii) the contribution of an individual firm to the global trend growth (η) and (iii) the elasticity of the common trend to country-specific R&D. We perform a sensitivity analysis by studying how the long-run effects of the global fiscal stimulus (the one that was shown to be the most effective in stimulating GDP growth) are affected by changes in the three parameters. Since we focus on the long-run effects of the fiscal stimulus, we do not distinguish between the case of Taylor rule and FG and simply report the long-run results.[20] Specifically, we first set the relative weight of public capital to 0.2, as opposed to 0.1. We do so by keeping the weight on private capital unchanged, and lowering the weight on labor correspondingly. Second, we increase η by 10% everywhere. Third, we consider an increase in γ^{US} of 0.1pp, from 0.4 to 0.5. As the γ's must sum up to one, we correspondingly reduce other countries' γ's by one third each. Table 7 reports the results. A larger weight of public capital in firms' production increases the effectiveness of the fiscal stimulus, both in the case of a US-only increase in public investment and in the case of a coordinated

[20] For the same reason we do not perform a sensitivity analysis on the R&D investment adjustment cost parameter, $\psi_{R\&D}$, as changes in its calibration only affect the transitional dynamics to the new steady state.

fiscal expansion. Conversely, results are not crucially affected by an increase in the contribution of an individual firm to the global trend, nor by a larger elasticity of the trend to US R&D.

5 Conclusions

This paper has addressed the secular stagnation from a multi-country perspective. We find that unfavorable technology developments can be at the core of the global growth slowdown. We also find that the stagnation can be counterbalanced by appropriate fiscal measures aimed at favoring R&D accumulation. Monetary policy can be a useful complementary lever to favor global growth in the short run, particularly if monetary accommodation is coordinated across countries (regions in our model). Moreover, leaving the burden of enacting an expansionary fiscal-monetary policy mix on one region only results in 'excess savings' in the other regions that hurt their short-term growth prospects and significantly reduce the long-run benefits in terms of higher global growth and interest rates. Expansionary fiscal and monetary policies adopted by all regions can counterbalance the negative short-run spillovers arising from a unilateral fiscal expansion and also enhance long-run world economic growth. Addressing the supply-side headwinds at the core of the secular stagnation with a globally coordinated policy response remains therefore clearly superior in terms of mitigating the output losses.

The paper can be extended along several directions. First, one can allow for the ZLB to constrain monetary policy, thus calling for non-standard measures that directly reduce long-term interest rates. Second, one can consider fiscal measures that would directly affect R&D efficiency (the shock at the basis of secular stagnation in this paper), such as taxes or incentives. We leave these issues for future research.

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Table 1: Households and firms behavior

	EA	US	CH	JP	RW
Households					
Subjective discount factor	0.995	0.995	0.995	0.995	0.995
Intertemporal elasticity of substitution	1.00	1.00	1.00	1.00	1.00
Habit persistence	0.60	0.60	0.60	0.60	0.60
Inverse of the Frisch elasticity of labor	2.00	2.00	2.00	2.00	2.00
Depreciation rate of capital	0.025	0.025	0.025	0.025	0.025
Depreciation rate of R&D	0.025	0.025	0.025	0.025	0.025
Final consumption goods					
Substitution btw domestic and imp. goods	2.50	2.50	2.50	2.50	2.50
Bias toward domestic goods	0.70	0.70	0.60	0.60	0.90
Substitution btw tradables and nontrad.	0.50	0.50	0.50	0.50	0.50
Bias toward tradable goods	0.50	0.50	0.50	0.50	0.50
Final investment goods					
Substitution btw domestic and imp. goods	2.50	2.50	2.50	2.50	2.50
Bias toward domestic goods	0.60	0.60	0.50	0.70	0.80
Substitution btw tradables and nontrad.	0.50	0.50	0.50	0.50	0.50
Bias toward tradable goods	0.90	0.90	0.90	0.90	0.90
Intermediate tradable goods					
Bias toward private capital	0.30	0.30	0.40	0.30	0.40
Bias toward public capital	0.10	0.10	0.10	0.10	0.10
Intermediate nontradable goods					
Bias toward capital	0.30	0.30	0.30	0.30	0.30
Bias toward public capital	0.10	0.10	0.10	0.10	0.10
R&D technology					
Elasticity of trend to regional R&D	0.30	0.40	0.10	0.20	–
Contribution of firm R&D investment to trend	0.23	0.18	0.42	0.35	–

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 2: Real and nominal rigidities

Real rigidities	
Investment adjustment	4.50
R&D Investment adjustment	4.50
Nominal Rigidities	
Households	
Wage stickiness	600
Manufacturing	
Price stickiness (domestically produced goods)	600
Price stickiness (imported goods)	6
Services	
Price stickiness	600

Note: in each region the corresponding parameter is set equal to the reported value.

Table 3: Gross price and wage markups

Manufacturing (tradables) price markup	1.20
Services (non-tradables) price markup	1.30
Wage markup	1.20

Note: in each region the corresponding parameter is set equal to the reported value.

Table 4: Monetary and fiscal policy rules

Monetary policy rule	
Interest rate inertia	0.87
Interest rate sensitivity to inflation gap	1.70
Interest rate sensitivity to output growth	0.10
Fiscal policy rule	
Lump-sum tax sensitivity to debt gap	2.01
Lump-sum tax sensitivity to debt growth	10.01

Note: in each region the corresponding parameter is set equal to the reported value.

Table 5: Steady state national accounts (% of GDP)

	EA	US	CH	JP	RW
Private consumption	54.0	54.0	51.0	54.0	52.0
Private investment in physical capital	21.0	21.0	25.0	21.0	25.0
Private investment in R&D	1.8	1.8	0.9	1.8	−−
Public consumption	20.0	20.0	20.0	20.0	20.0
Public investment	3.0	3.0	3.0	3.0	3.0
Imports	15.0	13.0	22.0	18.0	13.0
Consumption goods	9.0	7.0	11.0	13.0	5.0
Investment goods	6.0	6.0	11.0	5.0	8.0
Public debt (% of yearly GDP)	60.0	60.0	60.0	60.0	60.0
Share of world GDP	18.0	20.0	15.0	6.0	41.0

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 6: International linkages (% of GDP)

	EA	US	CH	JP	RW
Substitution btw consumption imports	2.50	2.50	2.50	2.50	2.50
Imported consumption goods from					
EA	...	1.3	1.6	1.1	1.7
US	1.9	...	1.9	1.3	1.3
CH	1.5	1.3	...	1.9	2.0
JP	0.5	0.4	1.3	...	0.4
RW	5.0	4.2	6.2	9.0	...
Substitution btw investment imports	2.50	2.50	2.50	2.50	2.50
Imported investment goods from					
EA	...	1.0	1.5	0.4	2.3
US	0.1	...	1.8	0.5	1.8
CH	1.0	1.0	...	0.7	2.8
JP	0.3	0.3	1.2	...	0.6
RW	3.6	3.2	5.7	3.6	...
Net foreign assets	0	0	0	0	0

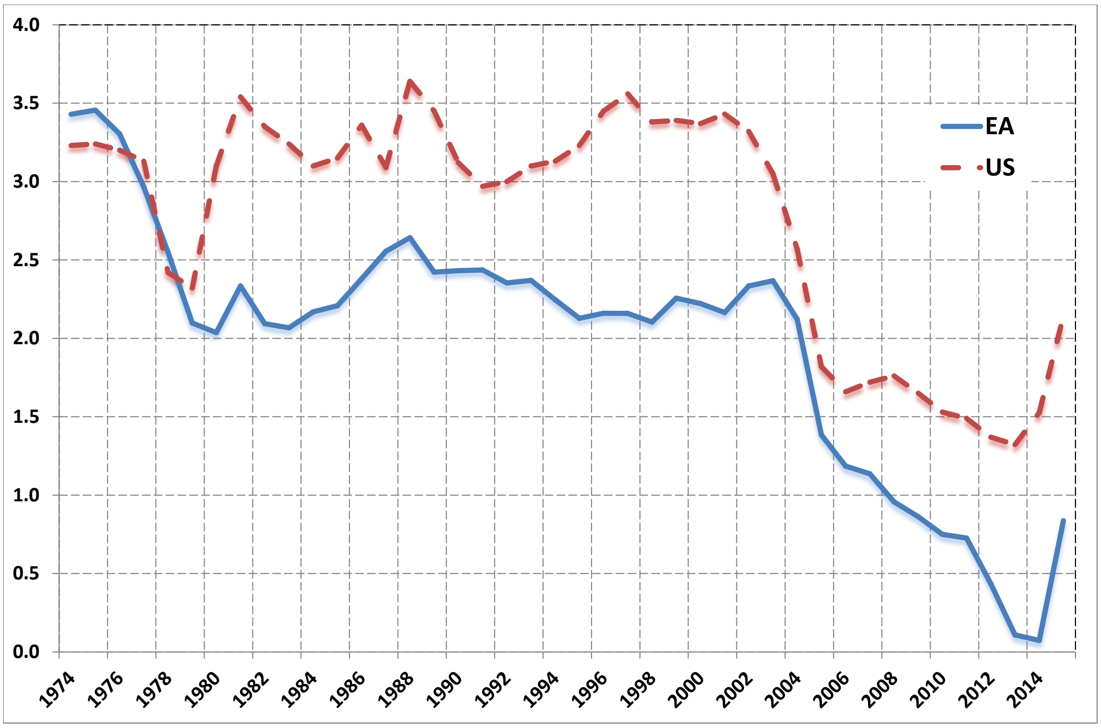
Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world.

Table 7: Global fiscal stimulus

	Benchmark		Sensitivity					
			High weight of K^G		High η		High γ^{US}	
	GDP	R	GDP	R	GDP	R	GDP	R
(1): Initial steady state	2.7	4.8	2.4	4.4	3.6	5.6	2.8	4.9
(2): Secular stagnation	1.8	3.8	1.6	3.7	2.6	4.7	1.9	4.0
difference (2)-(1)	-0.9	-1.0	-0.8	-0.8	-1.0	-1.0	-0.9	-0.9
(3): (2) + US pub. inv.	2.0	4.1	1.9	3.9	2.8	4.9	2.2	4.2
difference (3)-(2)	0.2	0.2	0.3	0.3	0.2	0.2	0.3	0.2
(4): (2) + global pub. inv.	2.3	4.4	2.3	4.4	3.1	5.2	2.4	4.5
difference (4)-(2)	0.5	0.5	0.7	0.7	0.5	0.5	0.5	0.5

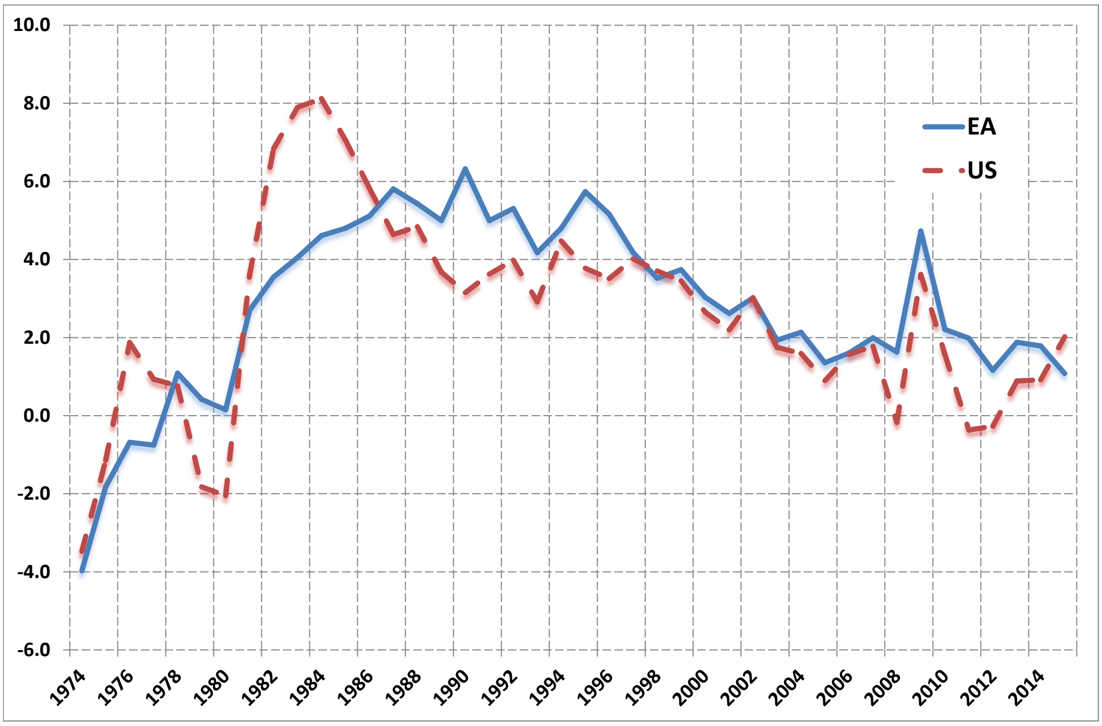
Note: GDP is growth rate of real GDP, in % points. Real interest rate (R) is in level (% points). "High weight of K^G": the weight of public capital is 0.2 (from 0.1). "High η": the elasticity of technology trend with respect to each individual firm' R&D is multiplied by 1.1. "High γ^{US}": the elasticity of technology trend with respect to US R&D is increased by 0.1pp and other "regional" elasticities are correspondingly decreased by 1/3 of a pp.

Figure 1: Secular stagnation. EA and US GDP



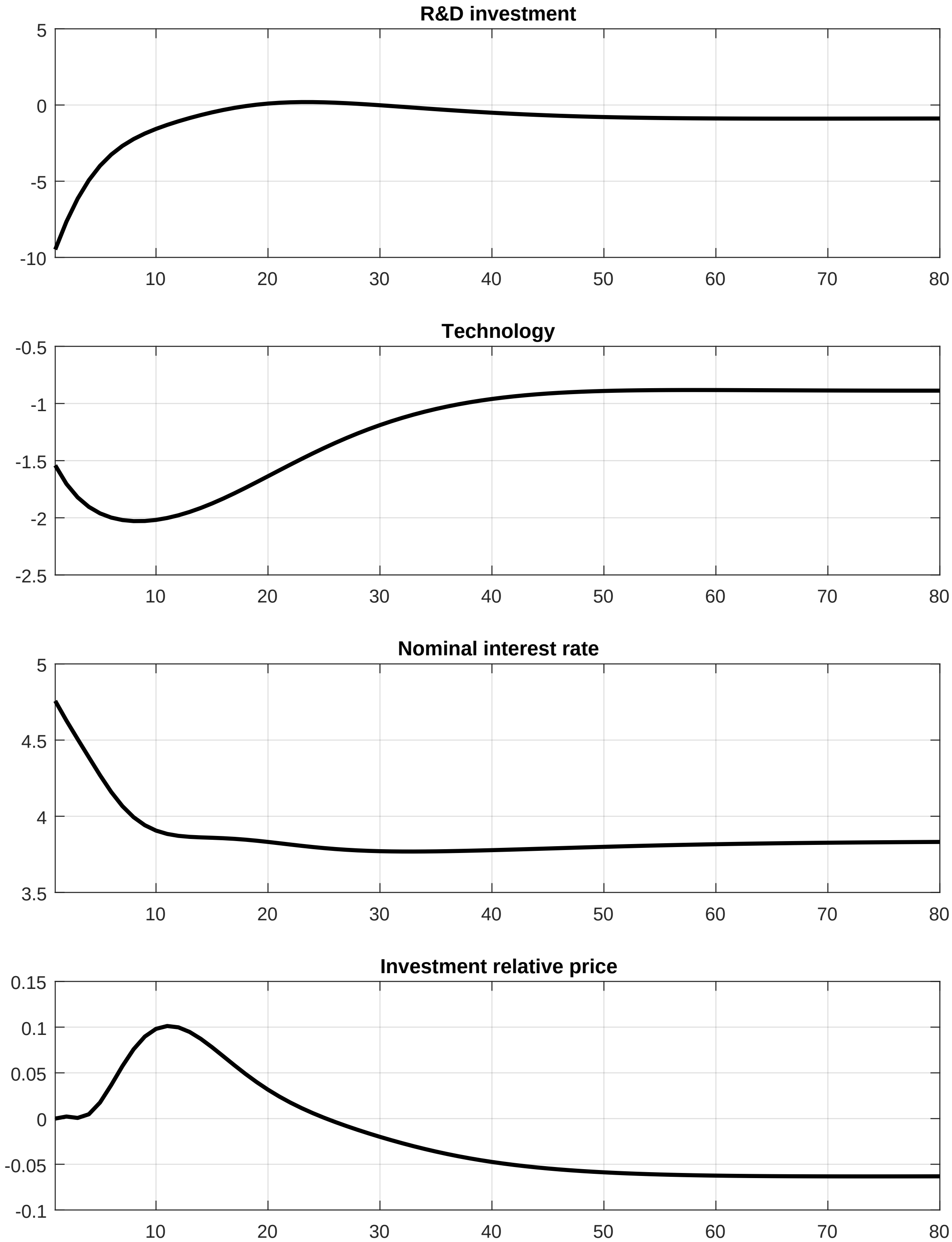
Note. GDP in real terms. Ten-year centered moving averages of annual growth rates, % points. Sources: St. Louis Fed FRED and Area Wide Model Dataset. EA= euro area; US= United States.

Figure 2: Secular stagnation. EA and US real interest rates



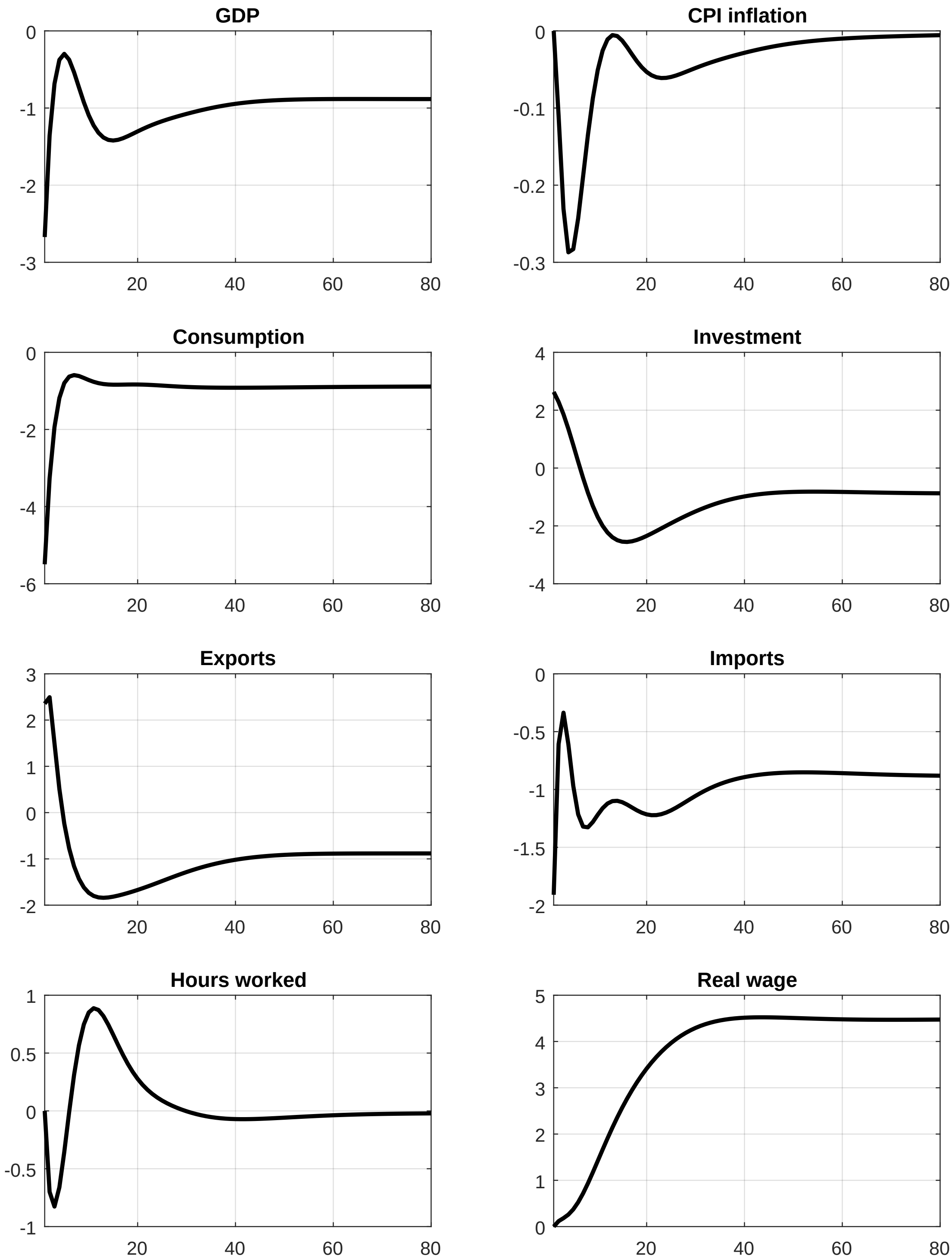
Note. Interest rates on ten-year government bonds, % points. Sources: St. Louis Fed FRED and Area Wide Model Dataset. EA= euro area; US= United States.

Figure 3: Secular stagnation. US variables and global technology



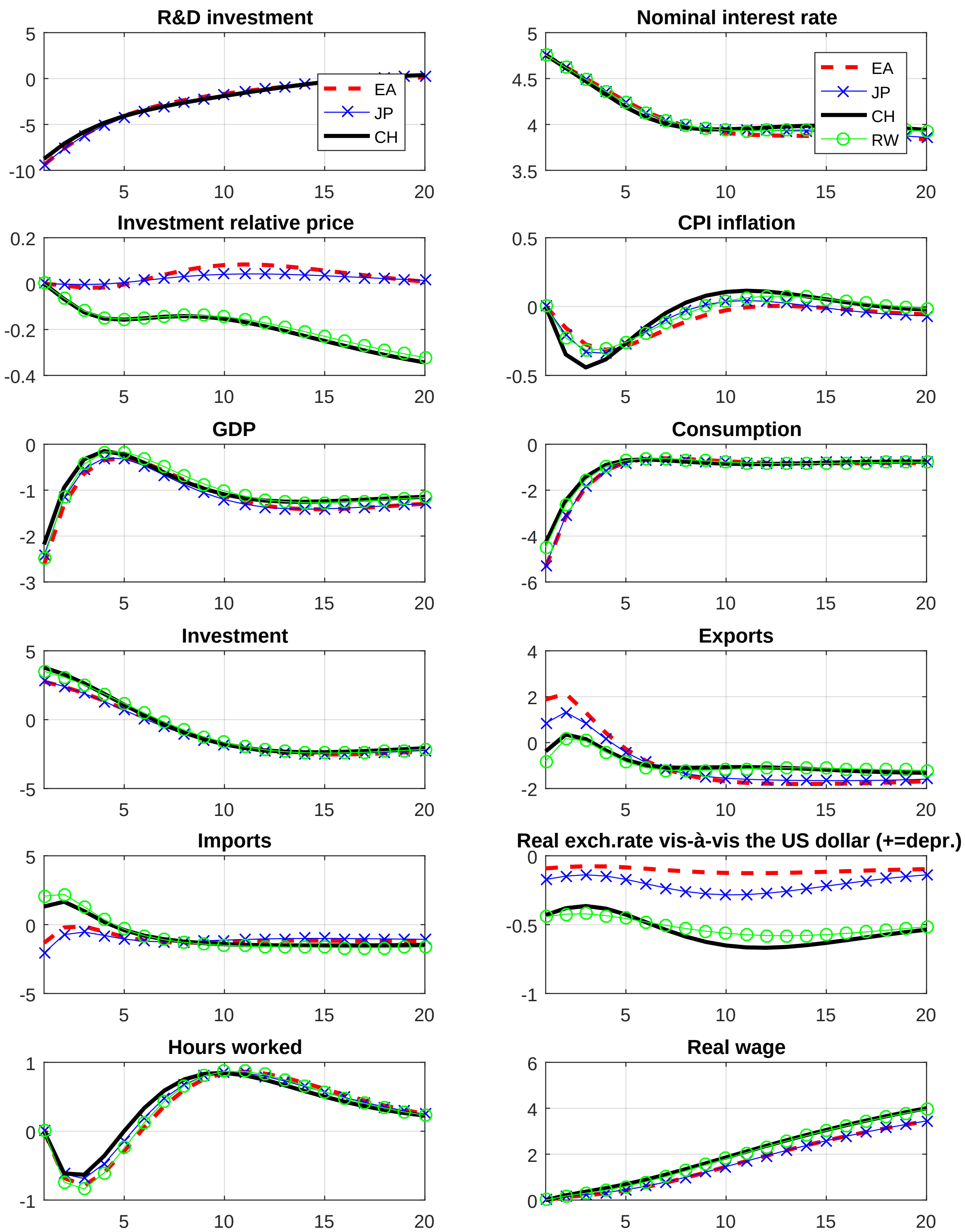
Note. Horizontal axis: quarters; vertical axis: R&D investment and labor-augmenting technology growth rates reported as annualized p.p. deviations from the pre-secular-stagnation steady state; nominal interest rate as annualized p.p.; investment relative price as % deviations.

Figure 4: Secular stagnation. US variables



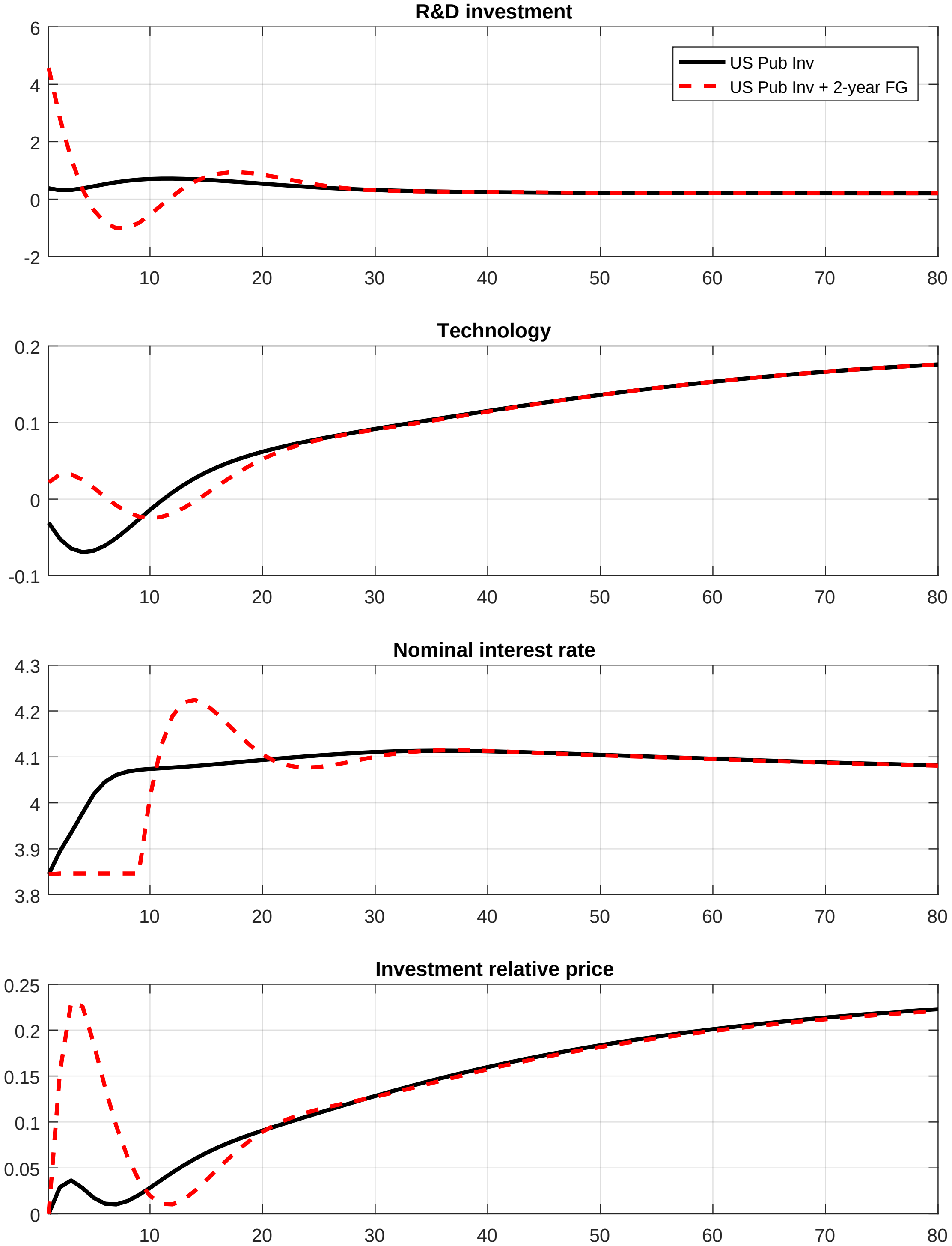
Note. Horizontal axis: quarters; vertical axis: real GDP and its components' growth rates as annualized p.p. deviations from the pre-secular-stagnation steady state; CPI inflation as annualized p.p. deviations; hours worked and real wage as % deviations.

Figure 5: Secular stagnation. EA, JP, CH, and RW variables



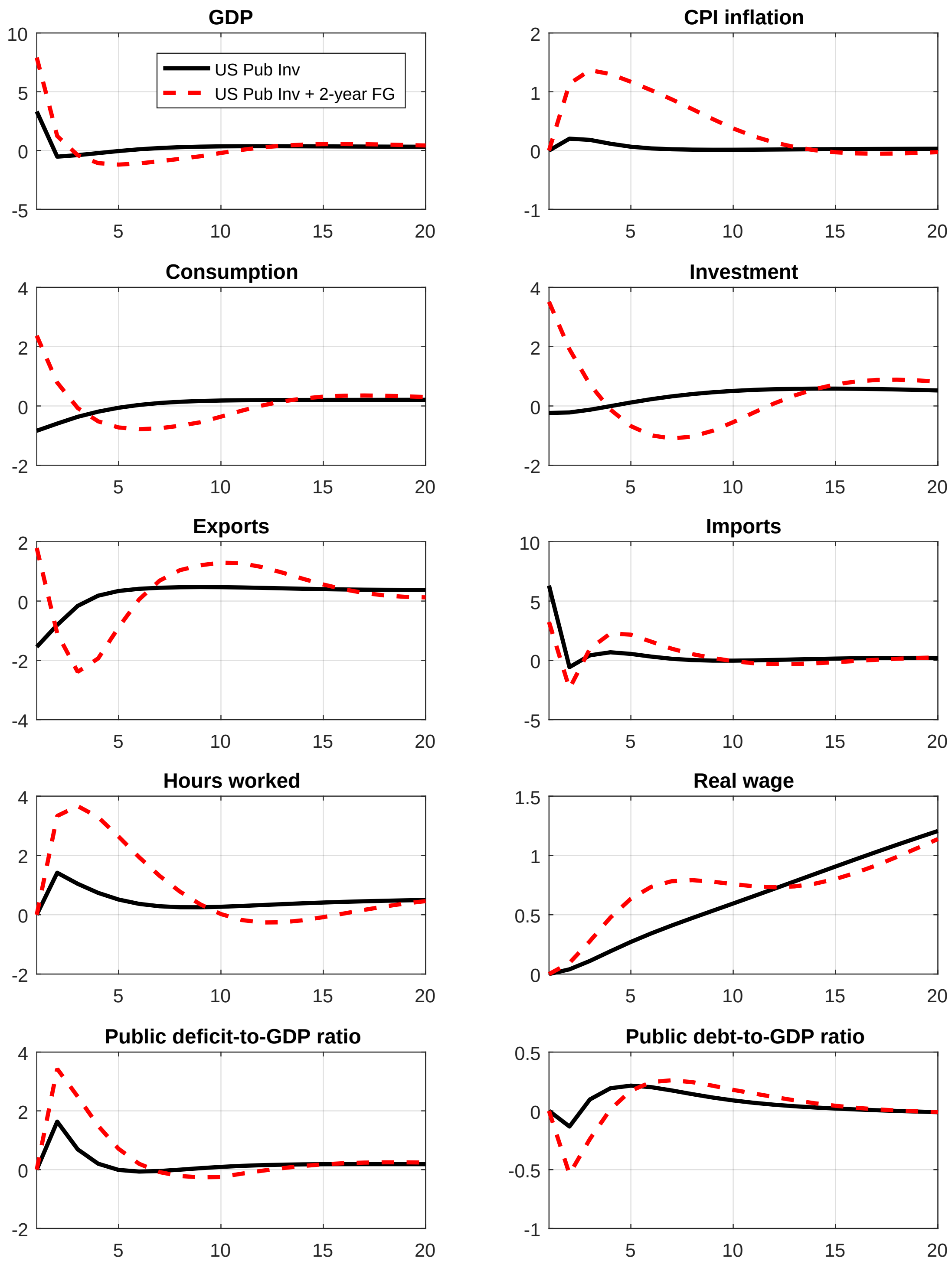
Note. Horizontal axis: quarters; vertical axis: real GDP and its components' growth rates as annualized p.p. deviations from the pre-secular-stagnation steady state; interest rate as annualized p.p.; CPI inflation as annualized p.p. deviations; investment relative price, real exchange rate, hours worked and real wage as % deviations.

Figure 6: Secular stagnation, US public inv. and monetary stance. US variables and global technology



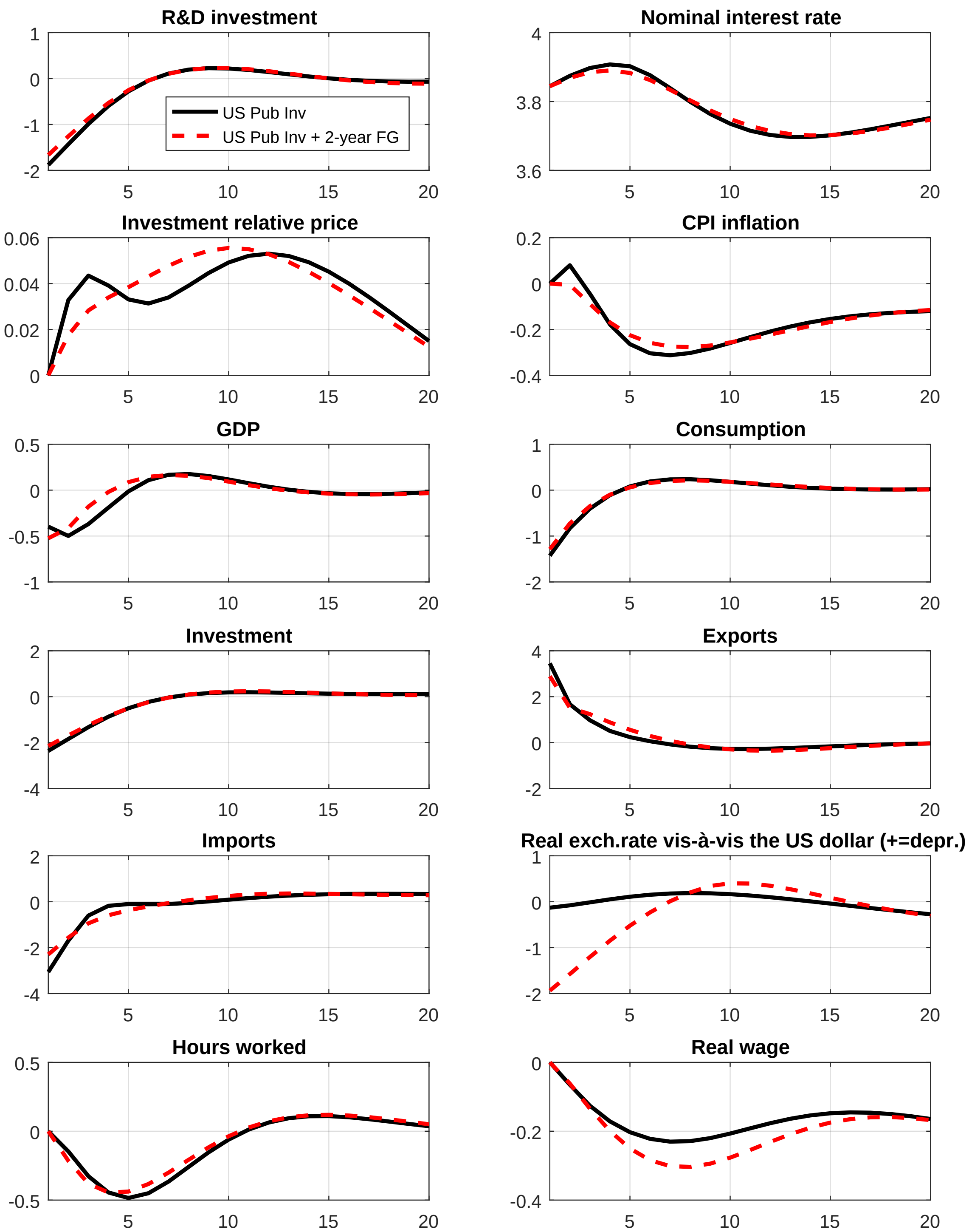
Note. Horizontal axis: quarters; vertical axis: R&D investment and labor-augmenting technology growth rates reported as annualized p.p. deviations from the secular-stagnation steady state; nominal interest rate as annualized p.p.; investment relative price as % deviations.

Figure 7: Secular stagnation, US public inv. and monetary stance. US variables



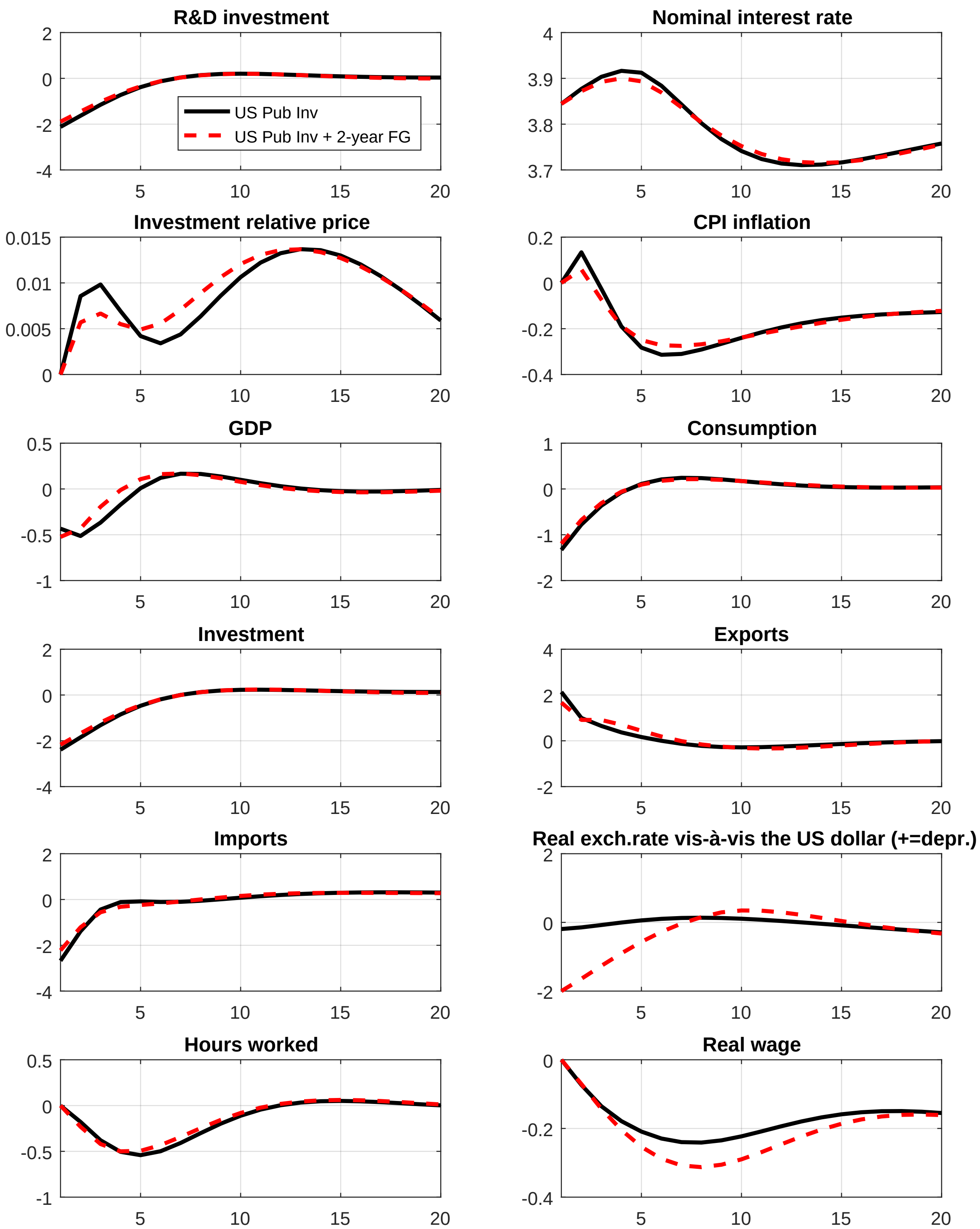
Note. Horizontal axis: quarters; vertical axis: real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; CPI inflation as annualized p.p. deviations; hours worked and real wage as % deviations; public deficit (ratio to GDP) and debt (ratio to annualized GDP) as p.p. deviations.

Figure 8: Secular stagnation, US public inv. and monetary stance. EA variables



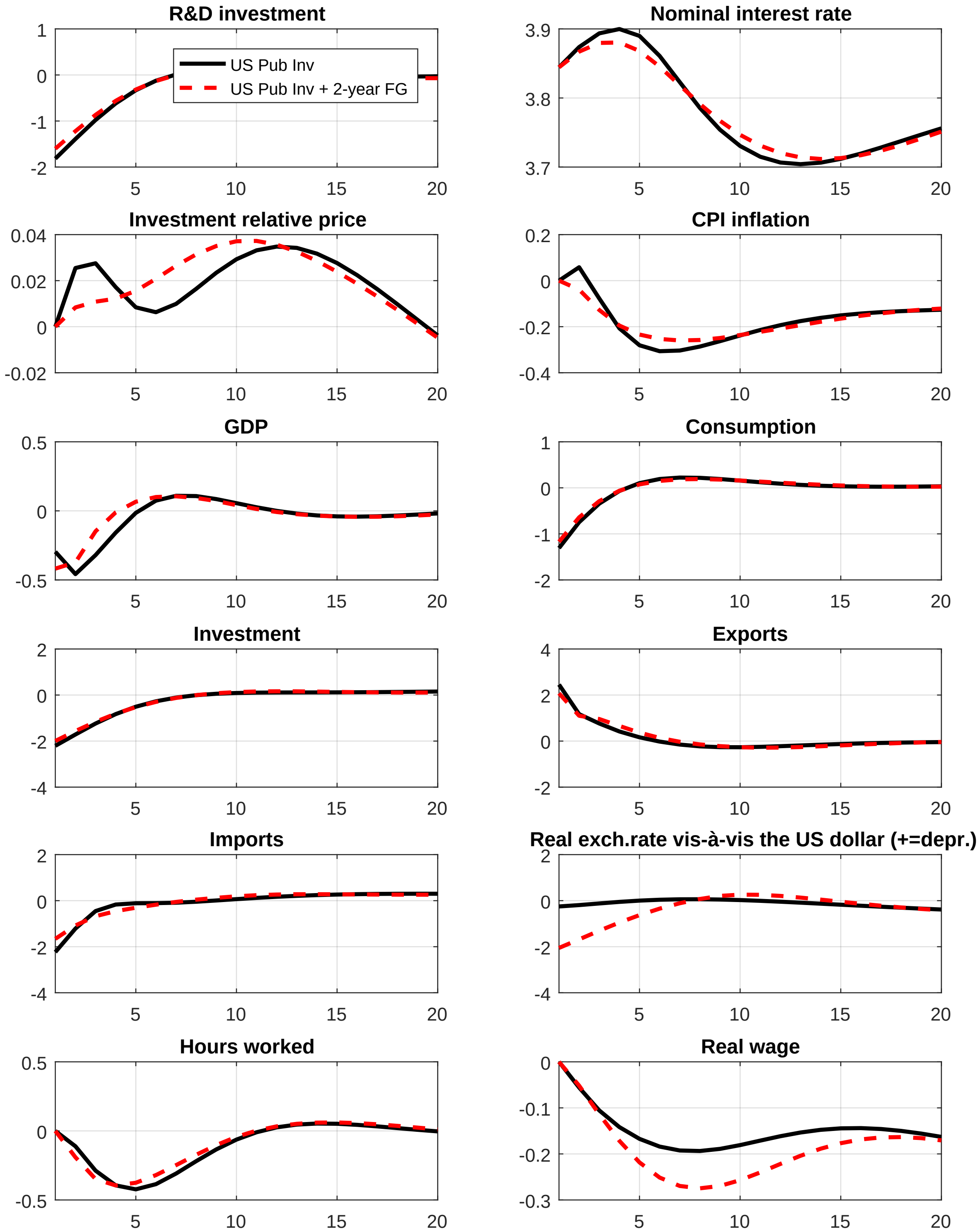
Note. Horizontal axis: quarters; vertical axis: real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; interest rate as annualized p.p. (level); CPI inflation as annualized p.p. deviations; investment relative price, real exchange rate, hours worked and real wage as % deviations.

Figure 9: Secular stagnation, US public inv. and monetary stance. JP variables



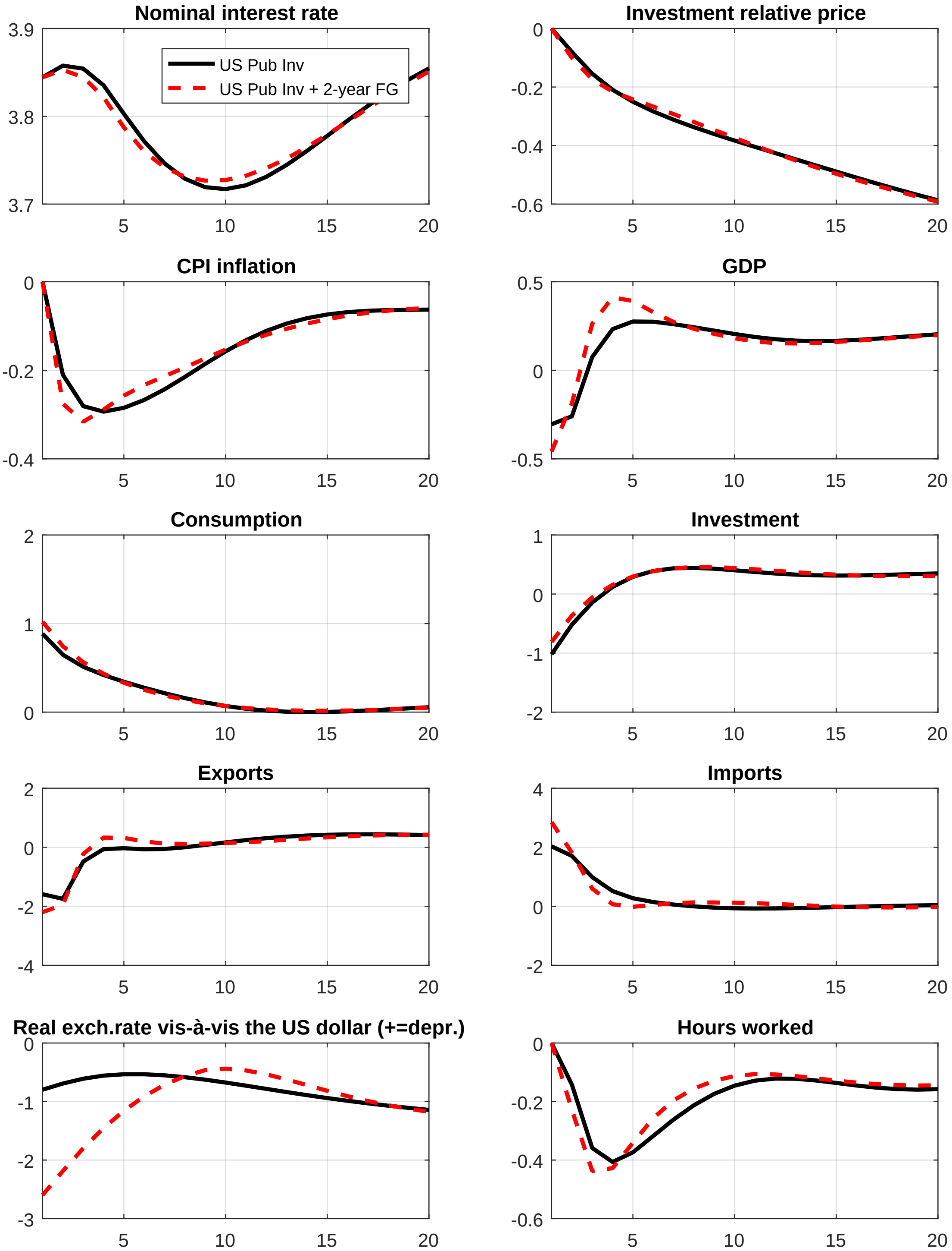
Note. Horizontal axis: quarters; vertical axis: real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; interest rate as annualized p.p. (level); CPI inflation as annualized p.p. deviations; investment relative price, real exchange rate, hours worked and real wage as % deviations.

Figure 10: Secular stagnation, US public inv. and monetary stance. CH variables



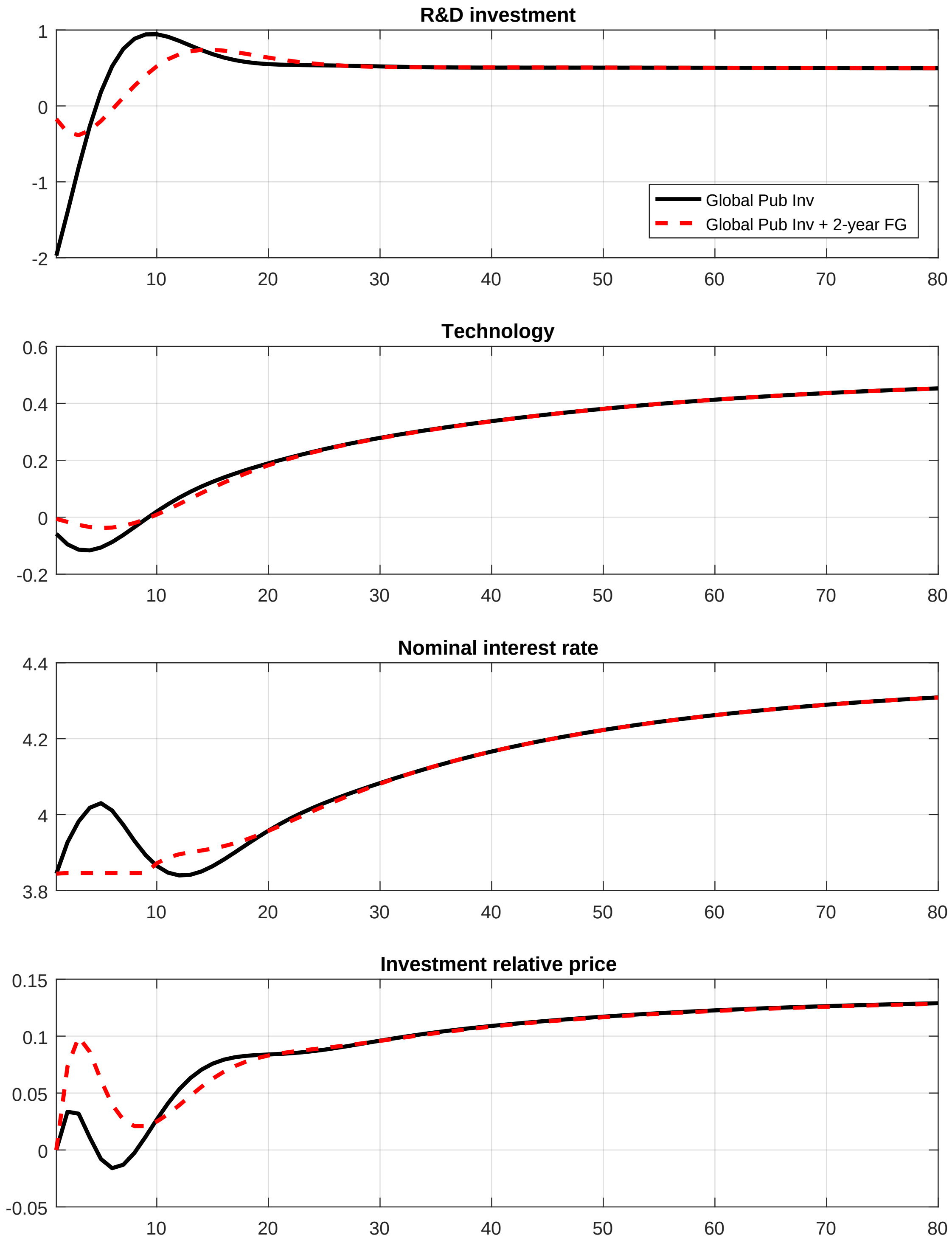
Note. Horizontal axis: quarters; vertical axis: nominal interest rate as annualized p.p.; real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; interest rate as annualized p.p. (level); CPI inflation as annualized p.p. deviations; investment relative price, real exchange rate, hours worked and real wage as % deviations.

Figure 11: Secular stagnation, US public inv. and monetary stance. RW variables



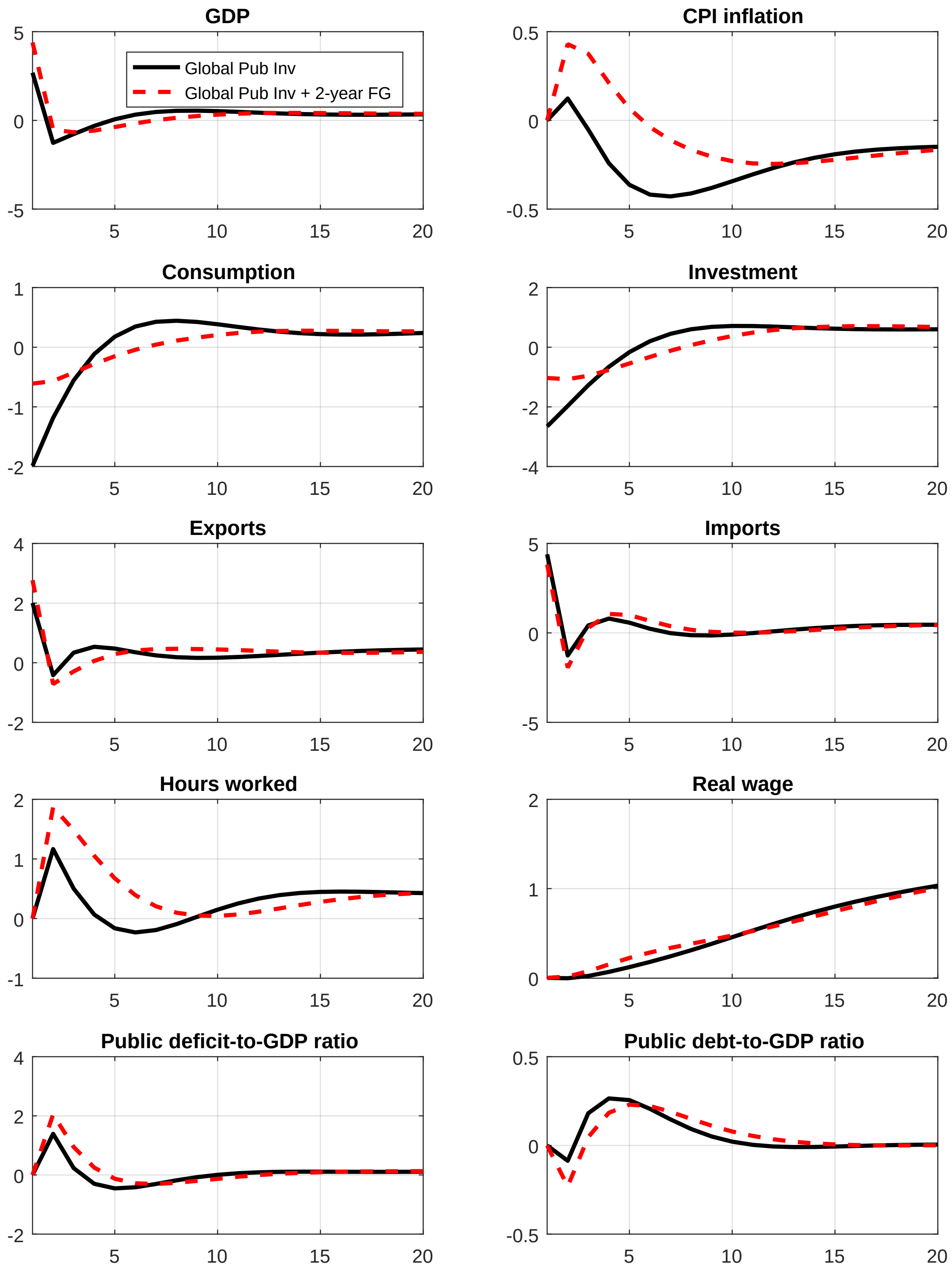
Note. Horizontal axis: quarters; vertical axis: real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; interest rate as annualized p.p. (level); CPI inflation as annualized p.p. deviations; investment relative price, real exchange rate, hours worked as % deviations.

Figure 12: Secular stagnation, global public inv. and monetary stance. US variables and global technology



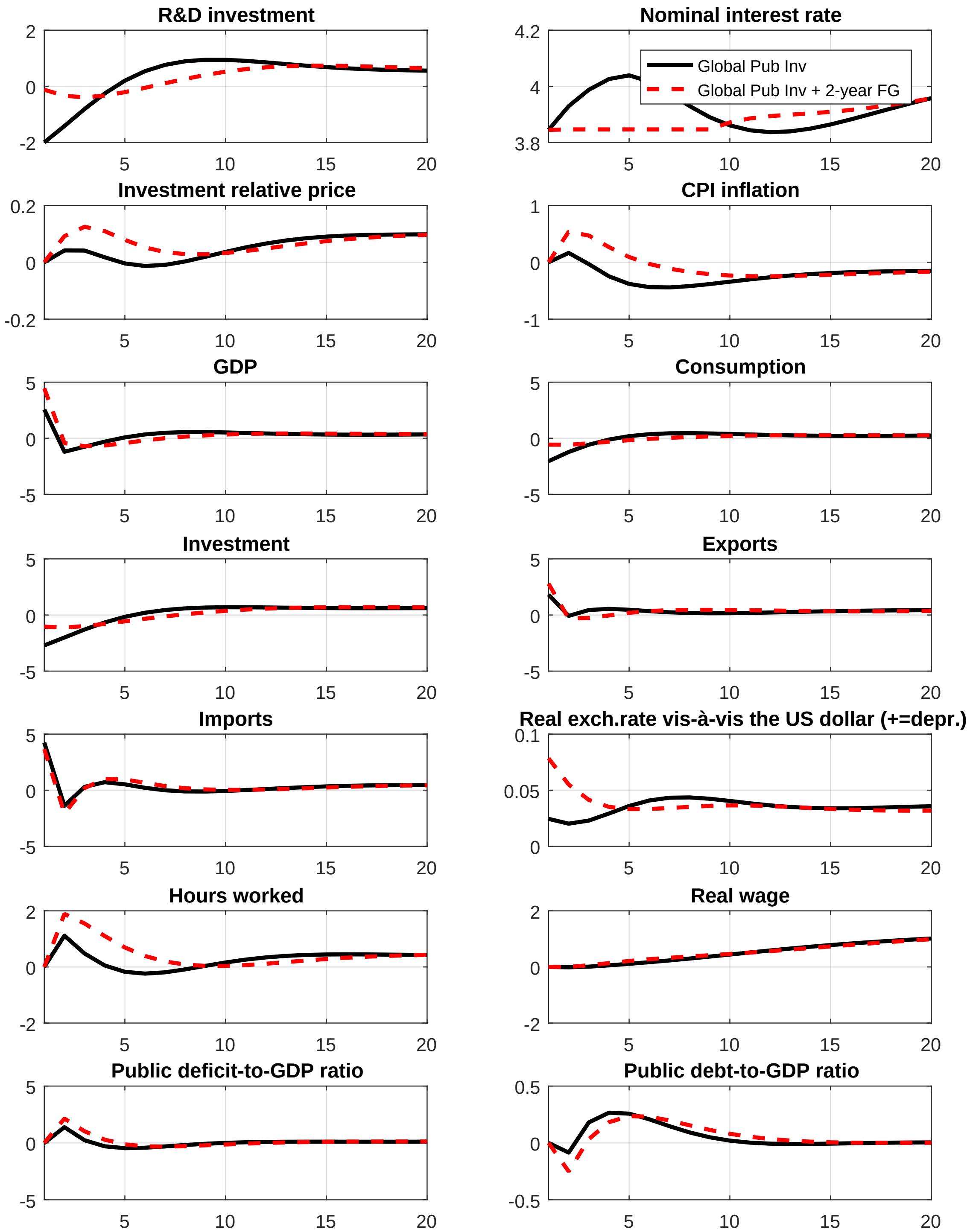
Note. Horizontal axis: quarters; vertical axis: R&D investment and labor-augmenting technology growth rates reported as annualized p.p. deviations from the secular-stagnation steady state; interest rate as annualized p.p. (level); investment relative price as % deviations.

Figure 13: Secular stagnation, global public inv. and monetary stance. US variables



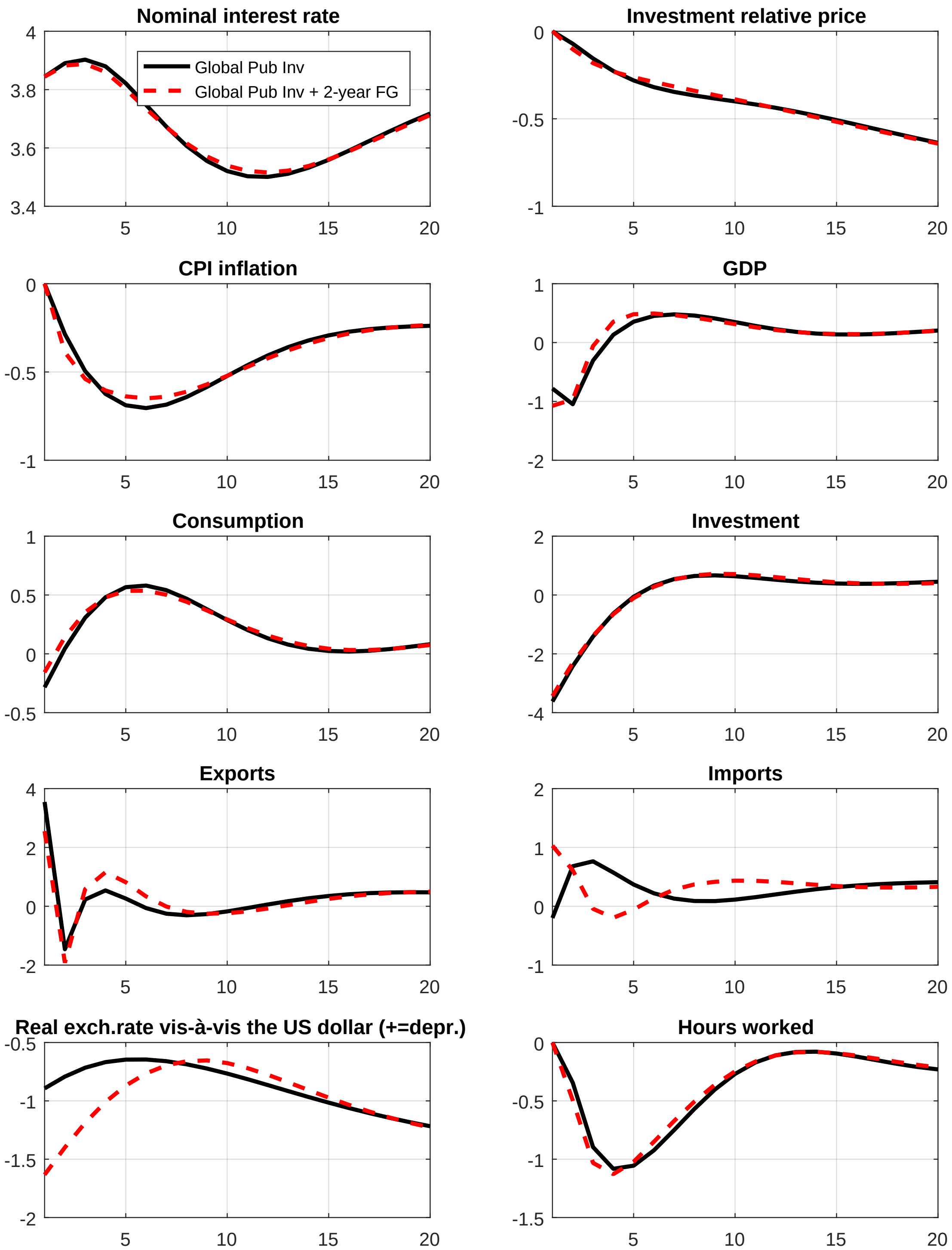
Note. Horizontal axis: quarters; vertical axis: real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; CPI inflation as annualized p.p. deviations; hours worked and real wage as % deviations; public deficit (ratio to GDP) and debt (ratio to annualized GDP) as p.p. deviations.

Figure 14: Secular stagnation, global public inv. and monetary stance. EA variables



Note. Horizontal axis: quarters; vertical axis: nominal interest rate as annualized p.p. (level); real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; CPI inflation as annualized p.p. deviations; hours worked and real wage as % deviations; public deficit (ratio to GDP) and debt (ratio to annualized GDP) as p.p. deviations.

Figure 15: Secular stagnation, global public inv. and monetary stance. RW variables



Note. Horizontal axis: quarters; vertical axis: nominal interest rate as annualized p.p. (level); real GDP and its components' growth rates as annualized p.p. deviations from the secular-stagnation steady state; CPI inflation as annualized p.p. deviations; hours worked and investment relative price as % deviations.

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