Secular stagnation, R&D, public investment and monetary policy: a global-model perspective

P. Cova A. Notarpietro P. Pagano M. Pisani*

April 26, 2017

Abstract

This paper evaluates the macroeconomic effects of monetary and fiscal measures aimed at counterbalancing secular stagnation forces. 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 rest of the world (RW) is simulated. The model features endogenous R&D accumulation, that affects global growth. Our main results are as follows. First, a negative efficiency shock to R&D investment contributes to explain the slowdown in long-run worldwide growth and the decrease in the interest rates observed in the data. Second, a permanent increase in US public infrastructure investment favors long-run world economic growth, by inducing firms to permanently increase investment in R&D; in the short run it stimulates domestic activity of Home but reduces activity abroad, because other countries increase savings to finance higher US aggregate demand. Third, an accommodative monetary stance enhances the short-run domestic macroeconomic effectiveness of US public investment, without inducing, overall, additional international spillover effects. Fourth, EA, JP, and CH, by simultaneously increasing public investment can further enhance long-run world economic growth. By adopting accommodative monetary policy stances, they can counterbalance the negative US short-run spillovers. Overall, coordinating worldwide expansions in domestic aggregate demands is growth-enhancing.

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

*Preliminary. Please do not circulate. Comments are welcome. Bank of Italy. The opinions expressed are those of the authors and do not reflect views of the Bank of Italy. Any remaining errors are the sole responsibility of the authors. Corresponding author: Pietro Cova. Economic Research and International Relations Area, Via Nazionale 91, 00184 Rome, Italy. Phone: +39 06 4792 2725, E-Mail: pietro.cova@bancaditalia.it.

...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

The relatively slow pace of the recovery in the United States (US) from the recent financial crisis has resurrected interest in Alvin Hansen's idea of secular stagnation (Hansen 1939). Given the increasing propensity to save and declining propensity to invest in recent years, the equilibrium (natural) real interest rate is persistently declining in the US.[2]

One version of the secular stagnation hypothesis is that the decline in the relative price of capital goods induced by technological innovation, despite having resulted in a substitution of capital for labour, may have played a role in lowering investment expenditure in nominal terms. Moreover, there can be negative repercussions on the long-run economys capacity for growth, due to poor expectations for demand in connection with population ageing.

A second version of the hypothesis, put forward notably by Bob Gordon (2015), does not consider demand and investment but instead focuses on the supply side, and in particular on the rate of growth of productivity, i.e. the economys 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. 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. Therefore, it is relevant to appraise the

[1]Draghi (2017)

[2]See Summers (2013, 2014, 2015a and 2015b) for a further exposition on the secular stagnation hypothesis.

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, an increase in public infrastructure investment in the US and other main industrialized countries, that, by stimulating aggregate demand and favoring capital accumulation, possibly in conjunction with an accommodative stance of the monetary policy, would help offset the excess worldwide savings with respect to investment and restore long-run growth.

This paper takes this "global" approach and evaluates, by simulating a dynamic general equilibrium model of the world economy with long-run endogenous growth, the impact of an increase in public infrastructure investment on the secular stagnation on long-run global growth and interest rates.

In the model, the world is composed of five blocs, calibrated to the euro area (EA), US, China (CH), Japan (JP), and the residual "rest of the world" region (RW). The model is New Keynesian,in that it features nominal rigidities and, as a consequence, allows for short-run macroeconomic stabilization role of monetary policy. In each region there are households that maximize utility with respect to consumption and leisure, and firms that maximize profits.

Crucially, the model features public infrastructure investment in each region and endogenous accumulation of R&D in the tradable sectors of US, EA, JP, and CH (the main worldwide investors in R&D in the data); the latter feature is a (rather) novel one for models of this type. The accumulated world stock of R&D positively affects the labor-augmenting technology trend growth and, thus, the growth rate of the world economy not only in the short run but also in the long run. The world economy follows a (long-run) balanced growth path, driven by the growth rate of worldwide (common to all regions) labor-augmenting technology.

Public infrastructure investment can be accumulated into public capital, so that public investment does affect 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 worldwide technology trend, whose growth rate positively depends on the pace of worldwide R&D accumulation. The latter depends upon firms in US, EA, JP, and CH intermediate tradable sectors optimally demanding 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.

The main methodological contribution of the paper is to fully endogenize the 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. The latter does not affect results in the long run because nominal prices become fully flexible (nominal rigidities hold only in the short run) and money neutrality is verified. The increase in public investment indirectly affects worldwide long-run 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. Moreover, along the long-run balanced growth path of the model there is a single worldwide (natural) interest rate, which holds in all regions and is proportional to the (long-run) growth rate of the economy.

Other features of the model are standard. In each country there is 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. International financial markets are incomplete, as only a riskless one-period bond, denominated in US dollars, is internationally traded.

We initially design a secular stagnation scenario (first scenario), in which, consistent with Gordon's secular stagnation supply-side view, the long-run growth rate of the labor-augmenting technology permanently decreases because of a negative shock to the worldwide 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).[3]

On top of the secular stagnation, we consider a permanent increase in US public infrastructure investment by 1% of (before-shock) GDP under two alternative assumptions on the US monetary policy stance: the US monetary authority follows the standard Taylor rule and, thus, allows for a gradual decrease in the policy rate to the new permanently lower level (second scenario); alternatively it immediately decreases the policy rate to the new lower long-run level thus adopting an accommodative monetary policy stance in the short run (third scenario).[4] 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, under a stance that front-loads the policy rate reduction to its new long-run level (fifth scenario).

All scenarios are simulated under perfect foresight, so 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 investment contributes to explain the slowdown in the long-run worldwide growth and the decrease in the interest rates observed in actual data. Second, a permanent increase in US public infrastructure investment favors a moderate strengthening of world economic growth in the medium and long run; in the short run, it stimulates domestic economic activity but reduces foreign activity, because other countries increase their savings to finance higher US (short-run) aggregate demand. Third, an accommodative stance of monetary policy enhances the short-run domestic macroeconomic effectiveness of US public investment, without inducing, overall, additional international spillover effects, because the additional increase in US aggregate demand and imports, due to the crowding-in of consumption and investment, compensates the larger US dollar depreciation. Fourth, EA, JP, and CH, by simultaneously increasing public investment and adopting an accommoda-

[3]The persistent decline in R&D efficiency is documented by Bloom et al. (2017).

[4]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. See International Monetary Fund (2017).

tive monetary policy, can counterbalance the negative US short-run spillovers and further enhance long-run world economic growth. Overall the scenarios presented in this section clearly speak in favor of coordinating worldwide expansions in domestic aggregate demands.[5]

The paper is organized as follows. Section 2 briefly describes the model, its equilibrium, and the calibration of its main parameters. 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 labor supply. 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 bonds pay 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

[5] In the simulations it is assumed that the zero lower bound (ZLB) on the monetary policy rate does not hold. However, in principle it should be the case that, even if the ZLB binds, in correspondence of an expansionary fiscal shock a front-loaded reduction of interest rates is more growth-friendly than a gradual one, thus shortening the time that the economy spends at the ZLB. Our simulations aim at analyzing the effectiveness of an increase in public investment to stabilize the economy in the short run under alternative stances of monetary policy. For an analysis of secular stagnation under a transitory liquidity trap, see Krugman (1998) and Eggertsson and Woodford (2003).

[6] For each region, size refers to the overall population and to the number of firms operating in each sector.

US dollar.[7]

Consumption and investment consist of final nontradable goods, which result from combining (constant-elasticity-of-substitution bundles of) nontradable and tradable intermediate goods.[8] The latter 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 two final nontradable goods (consumption and investment goods) and monopolistic firms that produce intermediate goods. The two final goods are sold domestically and are produced by combining all available intermediate goods, using a constant-elasticity-of-substitution (CES) production function. The two 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 technology, 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 worldwide technological trend, whose growth rate positively depends on the accumulated stock of (worldwide) R&D. Firms in the US, EA, JP, and CH intermediate tradable sectors optimally demand R&D in the domestic perfectly competitive market. There are R&D spillovers on the other sectors and to other countries, but each firm does not take them into account when optimally demanding R&D (R&D externality). The latter is supplied by domestic households, that accumulate it over time and optimally choose the amount of investment.

Finally, in each country there is a standard Taylor-type monetary policy rule. We also include adjustment costs on real and nominal variables, ensuring that

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

[8]The bundles of consumption, investment in physical capital, and investment in R&D can have different composition.

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, respectively. On the nominal side, quadratic costs make wages and prices sticky.[9]

In what follows we report the main equations associated with (private) R&D accumulation and public investment.

2.2 Firms' production function

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

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

where

$$\begin{aligned} TREND_t^{world} = {} & A\left(\left(R\&D_t^{US}(f)\right)^{\eta^{US}} \left(R\&D_t^{US}\right)^{1-\eta^{US}}\right)^{\beta_1} \\ & \left(\left(R\&D_t^{EA}(f)\right)^{\eta^{EA}} \left(R\&D_t^{EA}\right)^{1-\eta^{EA}}\right)^{\beta_2} \\ & \left(\left(R\&D_t^{JP}(f)\right)^{\eta^{JP}} \left(R\&D_t^{JP}\right)^{1-\eta^{JP}}\right)^{\beta_3} \\ & \left(\left(R\&D_t^{CH}(f)\right)^{\eta^{CH}} \left(R\&D_t^{CH}\right)^{1-\eta^{CH}}\right)^{1-\beta_1-\beta_2-\beta_3} \end{aligned} \tag{2}$$

and A is a scale parameter, $K_{T,t}^{US,P}(f)$ is the demand for private capital, $R\&D^{US}(f)$ the demand for the stock of $R\&D$, $K_{t-1}^{US,G}$ the public capital, and $L_{T,t}^{US}(f)$ represents the demand for labor supplied by domestic households. 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 $TREND$ is common among all sectors and countries. It 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 only takes into account its contribution to $TREND$ (measured by the parameter η, $0 < \eta < 1$)

[9]See Rotemberg (1982).

while the R&D accumulated by other individual firms and the aggregate R&D in each domestic and foreign sector (weighted by $1-\eta$) are taken as given. The parameters $\beta' s$ measure the elasticity of $TREND$ with respect to country-specific R&D ($0 < \beta_1, \beta_2, \beta_3 < 1$, $\beta_1 + \beta_2 + \beta_3 < 1$).

The US firm f optimally demands private capital, labor, and R&D, taking prices and the amount of public capital as given (firms do not demand public capital and there is no price or tariff paid for its use).

Firms in the US nontradable sector do not invest in R&D. They take the (worldwide common) labor-augmenting technology as given. They demand physical capital and labor supplied by domestic households, and take public capital as given. Production functions similar to those of US intermediate sectors hold in the other regions.

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

Following Bianchi et al. (2016), it is assumed that R&D is accumulated by US, EA, JP, and CH (but not RW) households and rented to firms in the domestic competitive markets. The US R&D is accumulated by the generic US household i according to

$$R\&D_t\,(i) = (1-\delta)\,R\&D_{t-1}\,(i) + Z_{I_{R\&D,t}} \left(1 - \frac{\psi_{R\&D}}{2}\left(\frac{I_{R\&D,t}}{I_{R\&D,t-1}} - gr_t\right)\right)^2 I_{R\&D,t}\,(i) \tag{3}$$

where $\psi_{R\&D} > 0$ 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). The term $Z_{I_{R\&D,t}}$ represents the shock to the marginal efficiency of R&D investment. Also, the term gr_t is the gross growth rate of the worldwide labor-augmenting technology trend,

$$gr_t \equiv \frac{TREND_t}{TREND_{t-1}}. \tag{4}$$

Similar laws of motion hold for EA, JP, and CH.

Finally, along the long-run balanced growth path the global real (natural) interest rate RR is pinned down by the growth rate gr and the subjective discount factor β,

$$RR = \frac{gr}{\beta}. \tag{5}$$

2.4 Public capital

In each region the fiscal authority exogenously decides the amount of investment in infrastructure and, thus, the accumulation of public capital. Thus, in every region the public capital $K_{G,t}$ is accumulated by the public sector according to

$$K_{G,t} = (1 - \delta_G) K_{G,t-1} + I_{G,t}, \tag{6}$$

where $0 < \delta_G < 1$ is the depreciation rate, and $I_{G,t}$ is public investment.[10]

The government budget constraint is

$$B_{G,t} - B_{G,t-1}R_{t-1} \leq (1 + \tau_t^c)P_{N,t}C_{G,t} + P_t I_{G,t} + TR_t - T_t, \tag{7}$$

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, $Tr_t > 0$ (< 0) are lump-sum transfers (lump-sum taxes) 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 $P_{N,t}$.[11] The investment in public capital $I_{G,t}$ is assumed to have a composition equal to that of private consumption, in line with existing literature. Thus, it is pre-multiplied by the consumption price deflator P_t.

The same (distortionary) tax rates apply to every domestic household. Total government revenues T_t from distortionary taxation are given by the identity

[10]For public capital projects with delay between the authorization of a government spending plan and the completion of an investment project, see Leeper et al. (2010) and Kydland and Prescott (1982).

[11]See Corsetti and Mueller (2006).

$$
\begin{aligned}
T_t \equiv & \int_0^n \tau_t^{\ell} W_t(j) L_t(j) \, dj \\
& + \int_0^n \tau_t^k R_t^k K_{t-1}(j) \, dj \\
& + \int_0^n \tau_t^c P_t C_t(j) \, dj
\end{aligned} \tag{8}
$$

where n is the population size of the country.

The government follows a fiscal rule defined on lump-sum transfers to bring the public debt as a % of domestic GDP, $b_G > 0$, in line with its long-run (steady-state) target $\bar{b}_G$.[12] The rule is

$$
\frac{TR_t}{TR_{t-1}} = \left(\frac{b_{G,t}^s}{\bar{b}_G^s} \right)^{\phi_1} \left(\frac{b_{G,t}^s}{b_{G,t-1}^s} \right)^{\phi_2}, \tag{10}
$$

where parameters ϕ_1, ϕ_2 are lower than zero, calling for a reduction (increase) in lump-sum transfer 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 transfers to stabilize public finance as they are non-distortionary and, thus, allow a "clean" evaluation of the macroeconomic effects of public investment.

Distortionary tax rates are kept constant at their corresponding baseline levels in all simulations.

[12]The definition of nominal GDP is

$$
GDP_t = P_t C_t + P_t^I I_t + P_t I_{R\&D,t} + P_t I_{G,t} + P_{N,t} C_{G,t} + P_t^{EXP} EXP_t - P_t^{IMP} IMP_t, \tag{9}
$$

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 (short-term) policy rate R_t according to a Taylor rule of the form

$$\left(\frac{R_t}{\bar{R}}\right)^4 = \left(\frac{R_{t-1}}{\bar{R}}\right)^{4\rho_R} \left(\frac{\Pi_{t,t-3}}{\bar{\Pi}^4}\right)^{(1-\rho_R)\rho_\pi} \left(\frac{GDP_t}{GDP_{t-1}}\right)^{(1-\rho_R)\rho_{GDP}}. \tag{11}$$

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 (GDP_t/GDP_{t-1}).

In some scenarios the reduction in monetary policy rate is assumed to be "front-loaded" , i.e., the central bank credibly and immediately reduces the policy rate to its new long-run level, instead of decreasing it in a gradual way according to the Taylor rule.

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 nontradable, intermediate tradable, and intermediate nontradable). 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, the fiscal rules, and the 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 main empirical evidence, follow the existing literature.[13]

Table 1 reports the model implied great ratios for the five regions.

Table 2 shows the implied preference and technology parameters. Preferences are the same across households of different regions. The habit parameter is set to 0.85, the intertemporal elasticity of substitution to 1.0 and the Frisch elasticity to 0.50. We further assume a quarterly depreciation rate of capital to 0.02, consistently with an annual depreciation rate of 8%.

As to final goods, the degree of substitutability between domestic and imported tradables is higher than that between tradables and nontradables, consistently with the existing literature. We set the (long-run) elasticity of substitution between tradables and nontradables to 0.5 and the long-run elasticity between domestic and imported tradables to 2.5.

Table 3 reports real and nominal rigidities. For real rigidities, parameters of the adjustment costs on investment changes are set to 3.5 in all countries. For nominal rigidities, we set the Rotemberg (1982) price and wage adjustment parameters in the tradable and nontradable sectors to 400. This value 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 weight of domestic tradable goods in the consumption and investment tradable baskets is different across countries, to match multilateral import-to-GDP ratios. In particular, we rely on the United Nations' Commodity Trade Statistics (COMTRADE) data on each region's imports of consumer and capital goods, to derive a disaggregated steady-state matrix delineating the pattern and composition of trade for all regions' exports and imports. We then set the weights of bilateral imports to match this trade matrix, reported in Table 4. It is interesting to note that trade with the RW region clearly dominates trade patterns for all other regions.

Table 5 shows price and wage markup values. We identify the intermediate nontradable and tradable sectors in the model with the services and manufacturing

[13] See, for example, Cova et al. (2015, 2016).

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 labor market, which are assumed to be equal. 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 6 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), gross inflation and output growth (see equation 11). For fiscal policy, the parameter governing the speed of speed of adjustment of public debt is assumed equal across countries and allows to stabilize the debt in the long run.

Finally, we set the discount factor so that the pre-shock steady-state annualized real interest rate is about 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 worldwide R&D investment efficiency, i.e., to the capability of converting investment into (accumulated) stock of R&D (see equation 3). 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) and induces a decline in the trend growth of worldwide labor productivity which matches the estimates by Conference Board (2015).[14]

On top of the secular stagnation (first scenario), we consider a permanent increase in US public investment by 1% of (before-shock) GDP under two alternative assumptions on the US monetary policy stance: the US monetary authority follows the standard Taylor rule and, thus, allows for a gradual decrease in the policy rate to the new permanently lower level (second scenario); alternatively, it immediately lowers the policy rate to the new (lower) long-run level (accommodative monetary policy in the short run, this the third scenario). Two other scenarios are simulated,

[14]The persistent decline in R&D efficiency is documented by Bloom et al. (2017).

where public investment is permanently increased in US, EA, JP, and CH under standard monetary policy stance (fourth scenario) or, alternatively, under a stance that front-loads the policy rate reduction to its new long-run level (fifth scenario).

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 worldwide labor-augmenting technology shock.

Figures 1 and 2 show the responses of the main US macroeconomic variables, conditional upon the negative shock to R&D accumulation.[15]

Because of the lower R&D investment efficiency, US 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).[16] The slower R&D accumulation permanently reduces the growth of technology. The latter determines the long-run growth rate of the world economy. Thus, the world economy converges to a new lower long-run balanced growth path. The nominal interest rate also permanently declines, to equalize savings and investments. The decline is gradual, consistent with the inertial term in the monetary policy rule. Inflation initially decreases and subsequently returns to its initial baseline level. 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. 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

[15]In the charts we report the first 80 quarters to show long-run responses. Alternatively, 12 quarters are reported when the emphasis is on the short-run effects, typically when the accommodative monetary policy stance is considered.

[16]The labor-augmenting technology, GDP and its components are reported as annualized p.p. deviations from the before-shock growth rate, the nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values, the investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

ex-ante real interest rate (not reported). The lower consumption makes resources available for higher investment in physical capital, which initially increases and, after around 8 quarters, decreases. Households initially substitute investment in physical capital for investment in R&D, because the latter is less efficient. Consistently with that, there is an initial increase in the relative price of investment in physical capital, followed by a permanent, mild decline. Exports growth initially increases, favored by the rise in investment in other countries (see below). Imports persistently decelerate, 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 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 3 reports 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. Consistently with observed exports and imports paths, the EA and JP real exchange rates vis-à-vis the US dollar appreciate less than the CH and RW counterparts. The R&D shock affects US, EA, JP and CH both "directly", because firms in those regions choose the amount of R&D, and "indirectly", through the labor augmenting technology. Instead, R&D affects RW only through the worldwide labor augmenting technology shock, as it is assumed that there is no R&D accumulation in the RW. 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 exchange rates vis-à-vis the CH and RW currencies, that benefits US, EA and JP exports. The reduction in the growth rates induces persistently 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.

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 worldwide economic activity, the permanent decrease in the interest rate and in the relative price of investment.[17]

The decrease in the growth rates is rather large in the short run, as prices cannot immediately adjust to the shock. Consistently, there is also a rather gradual and persistent decrease in the inflation rate and a gradual (and permanent) decrease in the monetary policy rate in all regions.

4.2 Increase in US public investment and front-loaded monetary policy reduction

Figures 4-5 show the responses of the main US variables' growth rates when the US fiscal authority permanently increases public investment by 1% of pre-shock GDP in correspondence of the secular stagnation shock (i.e., the negative shock to R&D accumulation).[18] Public investment in the other advanced countries is instead kept constant at its baseline level. The figures also report results obtained when the increase in US public investment is accompanied by an immediate sudden decrease in the US monetary policy rate to the new permanently (lower) level.

The US economy benefits from the fiscal and monetary policy measures in the short run. Both favor an increase in the US aggregate demand growth rate, counterbalancing the large short-run decline in economic activity observed in the secular stagnation scenario. Consistently, inflation declines to a lower extent than in the first scenario.

The increase in the US public investment indirectly favors the long-run growth rate as well. The larger public capital accumulation induces firms to increase R&D

[17]The decline in the trend growth of worldwide labor productivity matches the estimates by Conference Board (2015).

[18]In the charts, the label "sec stagn" stands for the secular stagnation scenario; the label "sec stagn and pub inv" for the scenario featuring both secular stagnation and public investment response; the label "acc US mon pol and pub inv" for the scenario featuring the secular stagnation, the public investment response and the accommodative monetary policy stance (front-loaded reduction in the policy rate).

at a faster rate. The latter favors a permanent increase in the labor-augmenting technology and, thus, a larger value of the worldwide growth rate. Consistently, the global and regional interest rates decrease less than in the stagnation scenario, because in the long run they are equal to each other and are proportional to the growth rate of the world economy.

Figures 6-9 report the spillovers on the EA, JP, CH, and RW economies, respectively. Compared to the stagnation scenario, the worldwide spillovers are positive in the long run, because of the positive impact of larger R&D on the growth rate. To the opposite, the spillovers are negative in the short run. Focusing, for example, on the EA (Figure 6), production growth decreases by more than in the secular stagnation scenario, because EA households lend to US households in order to finance the additional US growth rate induced by the increase in US public investments. As a consequence, compared to the secular stagnation scenario, both EA consumption and investment growth rates decrease. Exports and imports growth rates increase and decrease, respectively. The additional exports are associated with the larger US aggregate demand. In the case of "accommodative" US monetary policy, the real exchange rate appreciates vis-à-vis the US dollar, implying a negative price-competitiveness effect on the EA tradable goods. As suggested by Eggertsson et al. (2016), an aggressive monetary policy easing in one country makes secular stagnation worse in other countries, because of the negative effects on the latters' exports, associated with the appreciation of their exchange rate. Our results suggests that this expenditure switching effect can be somehow overruled if the aggressive monetary policy easing accompanies the expansionary fiscal shock. The reason is that it favors the crowding-in of private demand and, thus, imports from the trading partners.

Overall, we find that the mix of permanent increase in US public investment and front-loaded monetary policy reduction can counterbalance the short-run negative macroeconomic effects of secular stagnation. Public investment also favors long-run growth, by inducing R&D accumulation.

One caveat applies to our results. It is assumed that the ZLB on the monetary policy rate does not hold. However, in principle it should be the case that, even if the ZLB binds, a front-loaded reduction of interest rates is more growth-friendly than a gradual one, thus shortening the time that the economy spends at the ZLB.

Figures 7-9 show the macroeconomic effects on JP, CH, and RW variables. While the results for JP closely mimic those for the EA, two differences emerge when looking at the responses of CH and RW variables. In the short run, the Chinese export growth rate benefits substantially from the fiscal-cum-monetary US stimulus. This result also depends on the fact that the RW import growth rate sizably increases in the short run, as its exchange rate appreciates in real terms against all the other regions. This allows the RW, in the short run, to limit the fall in consumption growth, compared to the secular stagnation scenario, and thanks to the sharp fall in relative investment prices to maintain investment growth unaltered. The RW is thus the only region which in the short run benefits from the US expansionary policy mix. This is due to the fact that in the model the RW is the only region that does not directly contribute to worldwide growth via R&D accumulation. In the EA, JP, and CH households increase domestic savings to finance higher US R&D accumulation. This leads in the short run to a fall in their domestic capital accumulation rates. Given the complementarity between the physical and the R&D capital stock in their production functions, the short run adjustments in their investment rates are thus stronger compared to the RW.

4.3 Increase in US, EA, JP and CH public investment

Figures 10-16 show the responses of the main variables when, concomitant to the secular stagnation shock, the fiscal authorities of EA, US, JP, and CH simultaneously raise public investment. The increase is equal to 1% of GDP. Public investment in the RW is instead kept constant at its baseline level. Compared to the scenario with the US fiscal authority being the only one to increase public investment, GDP growth in EA, JP, and CH now rises more in both the short and long run. In the short run output growth benefits from the direct effect related to the increase in global public spending demand; in the medium and long term, it benefits from the endogenous supply-side effects induced by the additional increase in worldwide R&D activated by the surge in public infrastructure. Thus, thanks to the fiscal stimulus, R&D accumulation increases now also in EA, JP, and CH, not only in the US. Conversely, while also benefiting from higher GDP growth in the long run, the US now experiences a slower pace of GDP growth in the short run, compared to when it is the sole region to expand public infrastructure spending (cf. Figure 11 to Figure 5). This results from an overall lower share of worldwide savings being directed towards financing the US fiscal expansion. As now also EA, JP, and CH expand their respective public investments, their domestic savings are necessary to finance these expansions and the induced domestic R&D accumulations. Thus the US economy now has to rely more on its domestic 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 stronger downward adjustment in the monetary policy rate and a correspondingly higher real depreciation of the US dollar vis-à-vis the other regions' currencies. As a consequence export growth accelerates by more in the short run and import growth by less. The reverse occurs in the EA, JP, and CH which now export somewhat less and which need to import in order to sustain their stronger output growth rates. Thus import growth rate in these countries turns now positive in the short run, whereas it is negative when the public investment expansion solely occurs in the US. Positive import growth from the EA, JP, and CH benefits not only US exports, but also the RW's (Figure 16). Thus, notwithstanding the fact that the RW is now the only region which solely contributes to financing the worldwide expansion in world, and not only US, aggregate demand by further compressing its domestic demand, it now takes advantage from a stronger world demand for its exports (cf. Figure 16 and 9). This stronger world demand finally also determines on average higher global interest rates both in the short (except for the RW region) and in the long run, due to the stronger global growth rate induced by higher R&D accumulation.

We also consider the case of both a simultaneous increase in EA, US, JP, and CH public investment and front-loaded reductions in the monetary policy rates. The short-run growth rates of these regions are favored by this policy mix. There is crowding-in of consumption and investment, that favors international trade. However, this improvement in international trade occurs at the expense of the RW, as it now appreciates in real terms vis-à-vis the US, EA, JP, and CH. These regions' more aggressive monetary policy stances have thus beggar-thy-neighbor implications in the short run for the RW. Overall the scenarios presented in this section clearly speak in favor of coordinating worldwide expansions in domestic aggregate demands. Our results confirm, as advocated for example 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 it will entail some short run costs, as global savings, and hence lower domestic demands, are directed toward the country enacting the expansionary policies.

Overall, the simultaneous cross-country increase public investment favors worldwide activity in both short and long run because of the positive effects on US R&D. The short-run growth rate of the world economy can be further enhanced by a cross-country accommodative monetary policy stance in correspondence of the fiscal stimulus.

5 Conclusions

This paper has addressed secular stagnation from a multi-country perspective. Unfavorable technology developments at the core of the global growth slowdown documented in the literature can be counterbalanced by appropriate fiscal measures which are aimed at favoring R&D accumulation and can, thereby, enhance global growth in the long run. Monetary policy can be a useful complementary lever to favor worldwide growth in the short run, particularly if monetary accommodation is coordinated among all countries (all regions in our model). Moreover, leaving the burden of enacting an expansionary fiscal-monetary policy mix on one country 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 while also enhancing 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.

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, such as taxes or incentives. We leave these issues for future research.

References

[1] Bianchi, F., H. Kung, and G. Morales (2016). Growth, Slowdowns, and Recoveries, Duke University, mimeo.

[2] Bloom, N., C. I. Jones, J. Van Reenen, and M. Webb (2017). Are Ideas Getting Harder to Find?, Stanford University, mimeo.

[3] Conference Board (2015). Productivity brief 2015. Global productivity growth stuck in the slow lane with no signs of recovery in sight.

[4] Cova, P., P. Pagano, and M. Pisani (2016). Global macroeconomic effects of exiting from unconventional monetary policy. Temi di discussione (Economic working papers) 1078, Bank of Italy, Directorate General for Economics, Statistics and Research.

[5] Cova , P., P. Pagano, and M. Pisani (2015). Domestic and international macroeconomic effects of the Eurosystem expanded asset purchase programme. Temi di discussione (Economic working papers) 1036, Bank of Italy, Bank of Italy, Directorate General for Economics, Statistics and Research.

[6] Draghi, M. (2017). Welcome address by Mario Draghi, President of the ECB, at the joint conference by the ECB and the MIT Lab for Innovation Science and Policy "Fostering Innovation and Entrepreneurship in the Euro area", Frankfurt am Main, 13 March 2017.

[7] Eichengreen, B. (2015). Secular Stagnation: The Long View. NBER Working Paper No. 20836, January.

[8] Eggertsson, and M. Woodford (2016). The Zero Bound on Interest Rates and Optimal Monetary Policy. *Brookings Papers on Economic Activity,* vol. 1, pp. 139–211.

[9] Eggertsson, G., N. R. Mehrotra, and L. H. Summers (2016). Secular Stagnation in the Open Economy. *American Economic Review: Papers & Proceedings*, vol. 106(5), pp. 503–507.

[10] Finicelli, A., P. Pagano, and M. Sbracia (2013). Ricardian selection. *Journal of International Economics*, vol. 89(1), pp. 96–109.

[11] Gordon, R. (2015). Secular Stagnation: A Supply-Side View. *American Economic Review: Papers & Proceedings* vol. 105(5), pp. 54–59.

[12] Hansen, A. (1938), Speech published as A H Hansen (1939). Economic Progress and Declining Population Growth, *American Economic Review*, vol. 29, pp. 1–15.

[13] Kydland, F.E., and E.C. Prescott (1982). Time to build and aggregate fluctuations. *Econometrica*, vol. 50, pp. 1345–1370.

[14] International Monetary Fund (2017). IMF Investment and Capital Stock Dataset, 2017.

[15] International Monetary Fund (2014). Perspectives on Global Real Interest Rates. World Economic Outlook (April), chapter 3.

[16] Krugman, P. (1998). It's Baaack: Japan's Slump and the Return of the Liquidity Trap. Brookings Papers on Economic Activity, vol. 2:1998, pp. 137–205.

[17] Leeper, E., T.B. Walker, and S.C.S.Yang (2010). Government Investment and Fiscal Stimulus. *Journal of Monetary Economics*, vol. 57, pp. 1000–1012.

[18] Pagano, P., and M. Sbracia (2014). The secular stagnation hypothesis: a review of the debate and some insights, Questioni di Economia e Finanza (Occasional Papers) 231, Bank of Italy, Economic Research and International Relations Area.

[19] Rotemberg, J. (1982). Monopolistic Price Adjustment and Aggregate Output. *Review of Economic Studies*, Wiley Blackwell, vol. 49(4), pp. 517–31, October.

[20] Summers, Lawrence. 2013. "Why Stagnation Might Prove to be the New Normal." The Financial Times.

[21] Summers, Lawrence H. 2014. "U.S. Economic Prospects: Secular Stagnation, Hysteresis, and the Zero Lower Bound." Business Economics, vol. 49(2).

[22] Summers, Lawrence H. 2015a. "Demand Side Secular Stagnation." American Economics Review, Papers and Proceedings, vol. 105(5), pp. 60–65.

[23] Summers, Lawrence H. 2015b. "Lower Real Rates, Secular Stagnation and the Future of Stabilization Policy." Central Bank of Chile Annual Conference.

[24] Summers, Lawrence. 2016. "The Age of Secular Stagnation." Foreign Affairs, February.

Table 1: Steady state national accounts (%)

	EA	US	CH	JP	RW
Private consumption	54.3	58.5	38.8	55.1	56.7
Private investment	20.0	15.0	40.0	20.0	20.0
Public expenditure	20.0	20.0	20.0	20.0	20.0
Imports	23.8	14.3	22.2	14.8	19.2
Consumption goods	13.1	7.8	10.3	8.2	11.1
Investment goods	10.7	6.5	11.9	6.6	8.1
Public debt (% of yearly GDP)	92.8	102.7	26.1	238.0	80.8
Share of world GDP	14.1	21.1	14.9	9.2	40.7

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

Table 2: Households and Firms Behavior

	EA	US	CH	JP	RW
Households					
Subjective discount factor	0.9901	0.9901	0.9901	0.9901	0.9901
Depreciation rate	0.02	0.02	0.02	0.02	0.02
Intertemporal elasticity of substitution	1.00	1.00	1.00	1.00	1.00
Habit persistence	0.85	0.85	0.85	0.85	0.85
Inverse of the Frisch elasticity of labor	2.00	2.00	2.00	2.00	2.00
Tradable Intermediate Goods					
Bias toward capital	0.40	0.40	0.50	0.40	0.40
Non-tradable Intermediate Goods					
Bias toward capital	0.35	0.35	0.45	0.35	0.35
Final consumption goods					
Substitution btw domestic and imp. goods	2.50	2.50	2.50	2.50	2.50
Bias toward domestic goods	0.52	0.83	0.34	0.67	0.77
Substitution btw tradables and non-trad.	0.50	0.50	0.50	0.50	0.50
Bias toward tradable goods	0.50	0.50	0.60	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	0.28	0.59	0.24	0.47	0.60
Substitution btw tradables and nontr.	0.50	0.50	0.50	0.50	0.50
Bias toward tradable goods	0.50	0.50	0.70	0.50	0.50

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

Table 3: Real and nominal rigidities

Real Rigidities	
Investment adjustment	3.50
Nominal Rigidities	
Households	
Wage stickiness	400
Manufacturing	
Price stickiness (domestically produced goods)	400
Price stickiness (imported goods)	400
Services	
Price stickiness	400

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

Table 4: International linkages (% of GDP)

	EA	US	CH	JP	RW
Substitution between consumption imports	2.50	2.50	2.50	2.50	2.50
Imported consumption goods from					
EA	...	1.1	1.0	0.8	3.4
US	0.9	...	0.8	0.7	4.3
CH	1.3	1.4	...	1.8	2.5
JP	0.3	0.5	0.9	...	0.9
RW	10.5	4.9	7.6	5.9	...
Substitution between investment imports	2.50	2.50	2.50	2.50	2.50
Imported investment goods from					
EA	...	0.8	1.1	0.4	2.9
US	0.9	...	0.9	0.6	1.7
CH	1.2	1.3	...	1.4	2.7
JP	0.3	0.4	1.3	...	0.9
RW	8.4	4.0	8.6	4.3	...
Net foreign assets (%yearly GDP)	−17.6	−27.4	21.0	57.3	5.3
Net foreign assets (%yearly GDP) (1)	−0.4	13.3	−6.5	23.0	−9.9
Financial intermediation cost function ($\phi_1; \phi_2$)	$0.15; 0.3$	$0.15; 0.3$	$0.15; 0.3$	$0.15; 0.3$	$0.15; 0.3$

Note: EA=euro area; US=United States; CH=China; JP=Japan; RW=Rest of the world. (1) net of private and official holdings of USD and EUR government bonds

Table 5: (Gross) Price and wage markups

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

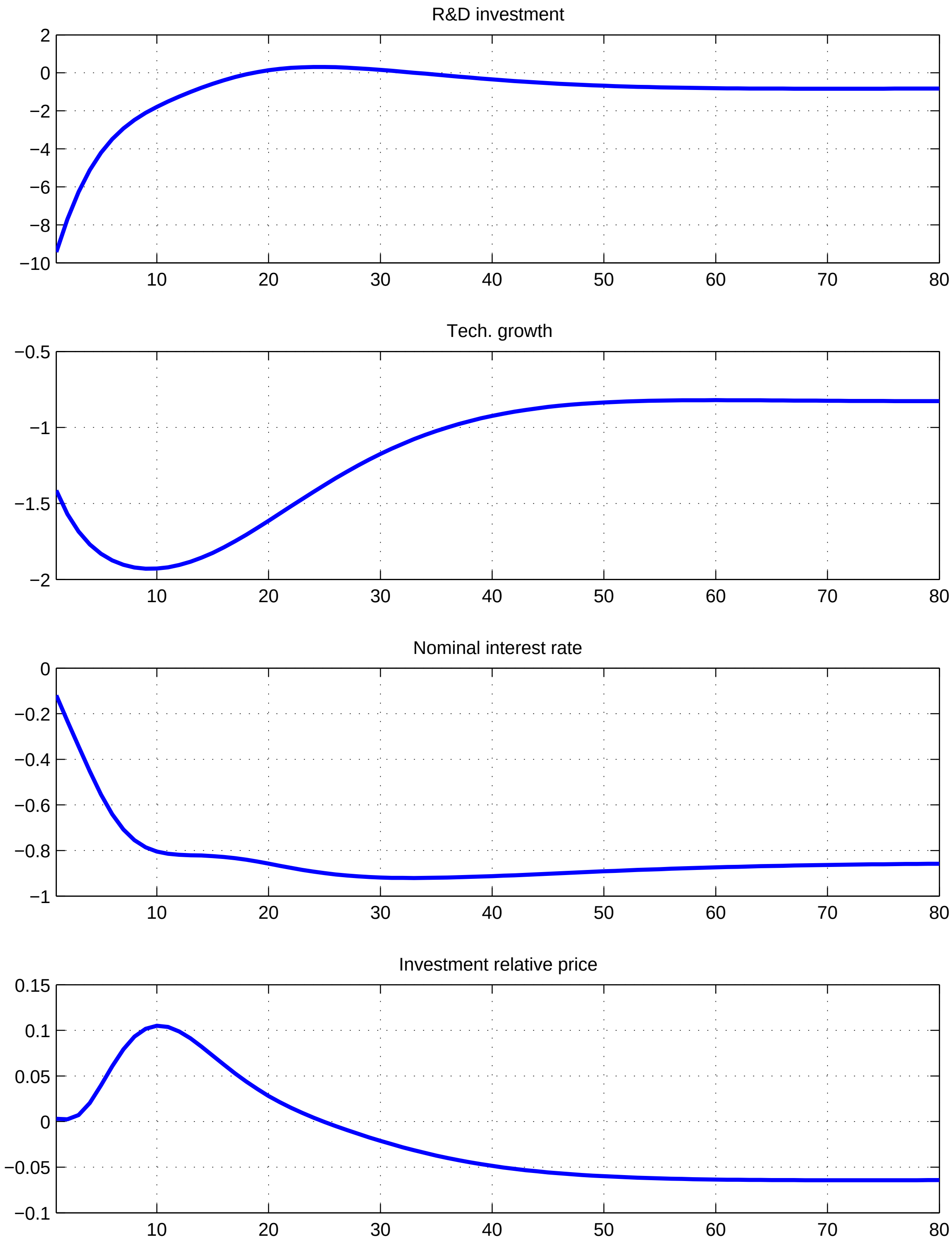
Note: in each region the corresponding parameter is set equal to the reported value.

Table 6: Monetary and fiscal policy

Inflation target	2%
Interest rate inertia	0.87
Interest rate sensitivity to inflation gap	1.70
Interest rate sensitivity to output growth	0.10
Lump-sum tax sensitivity to debt gap	0.60

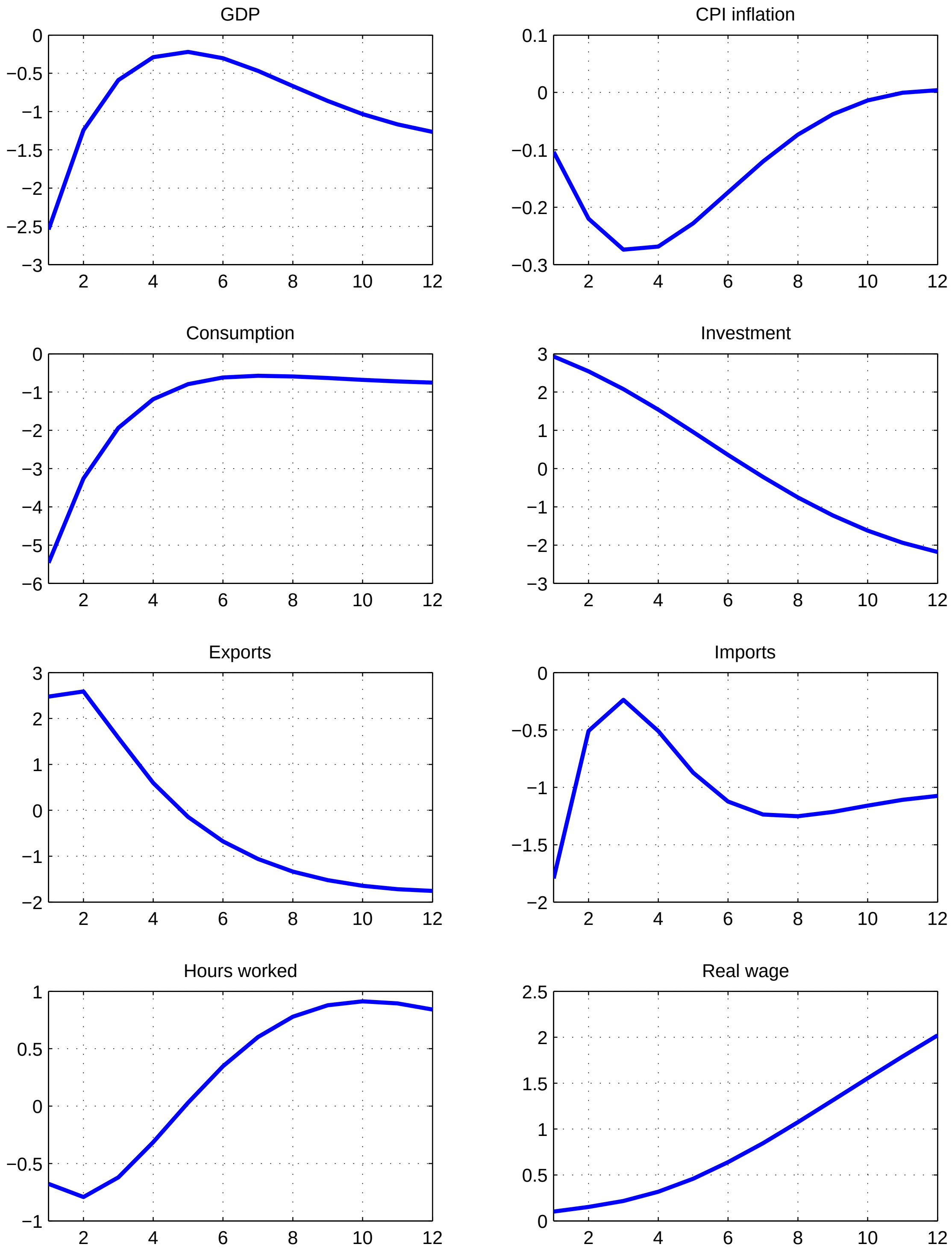
Note: in each region the corresponding parameter is set equal to the reported value.

Figure 1: Secular stagnation. US variables and global technology



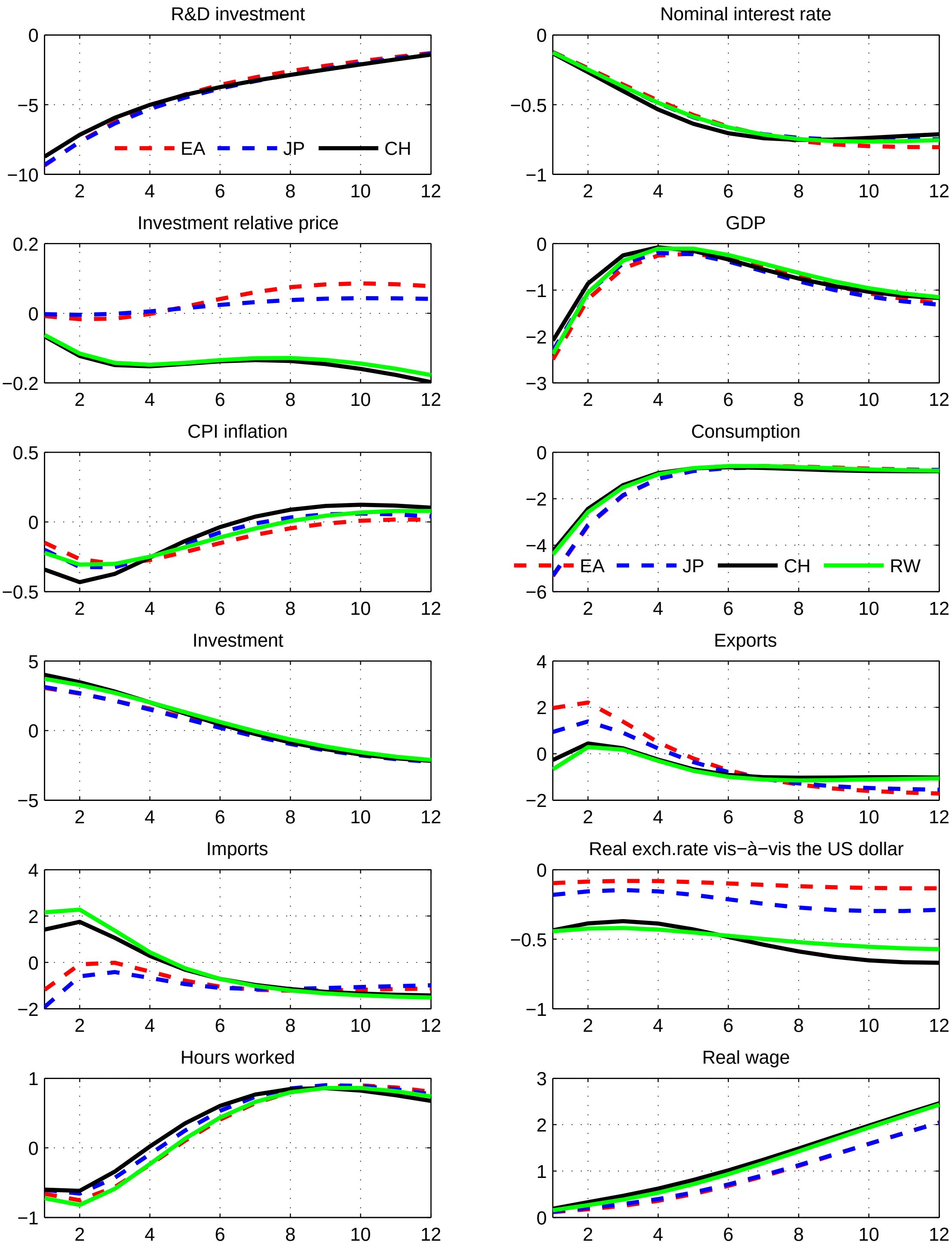
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

Figure 2: Secular stagnation. US variables



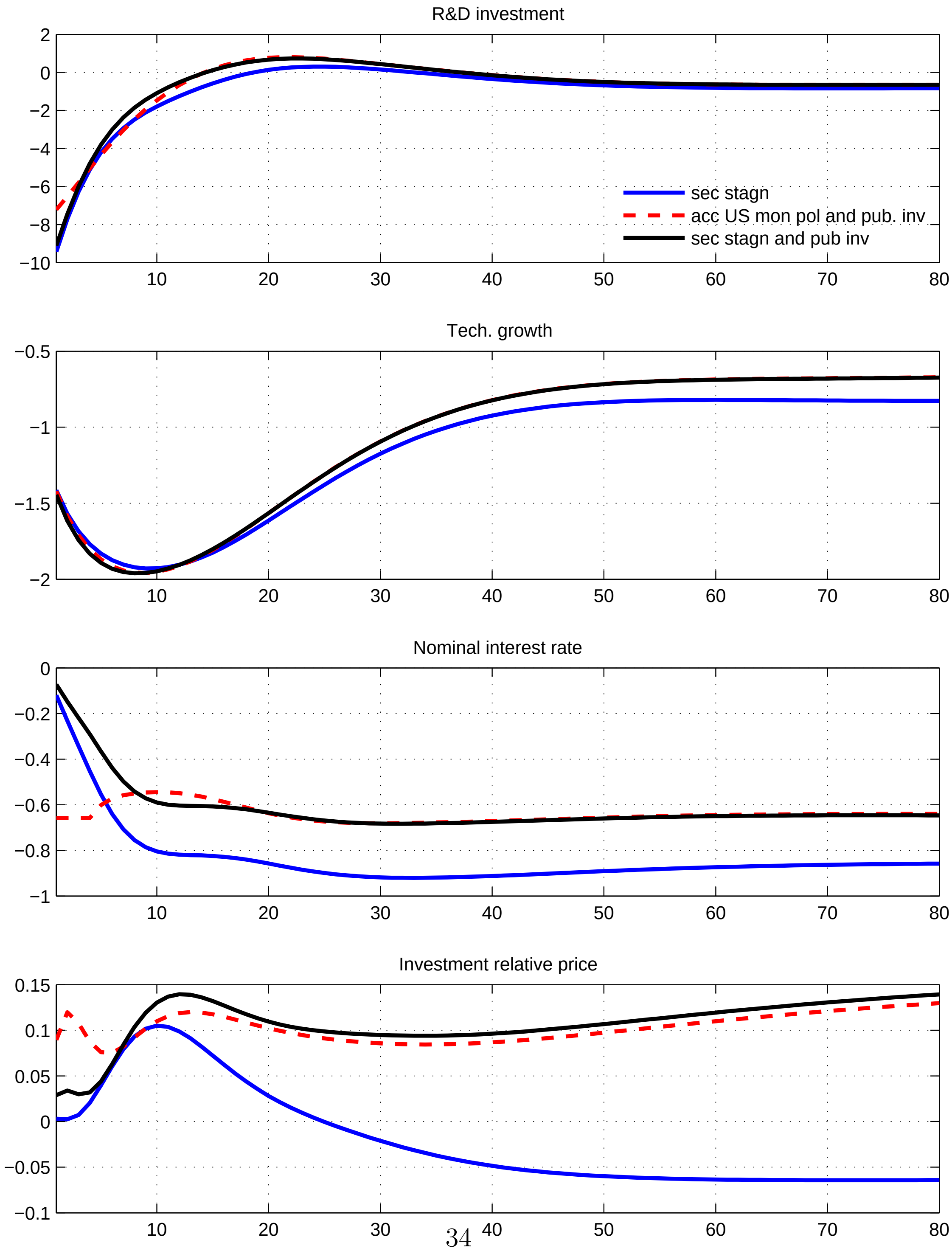
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

Figure 3: Secular stagnation. EA, JP, CH, and RW variables



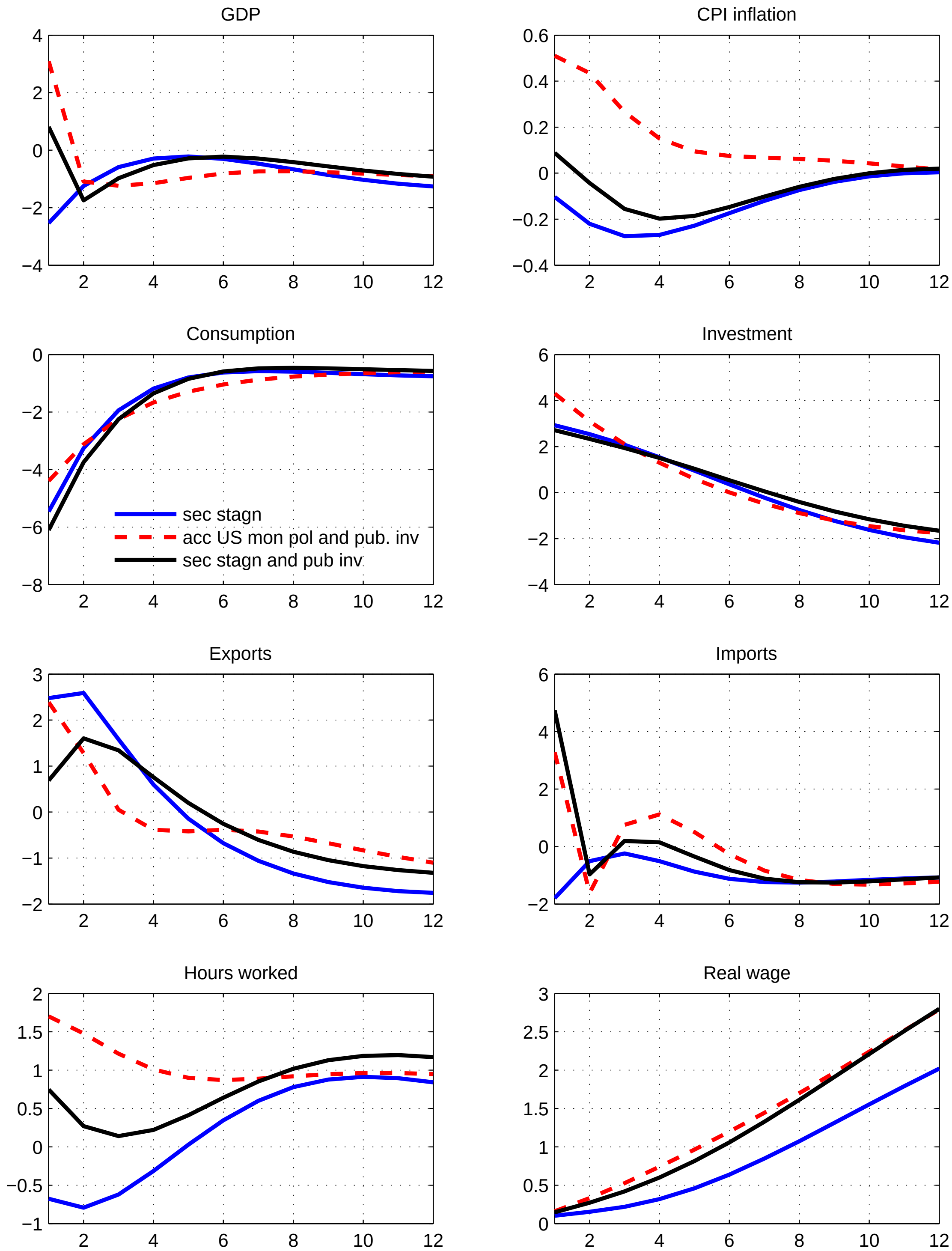
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

Figure 4: Secular stagnation, US public inv. and monetary stance. US variables and global technology



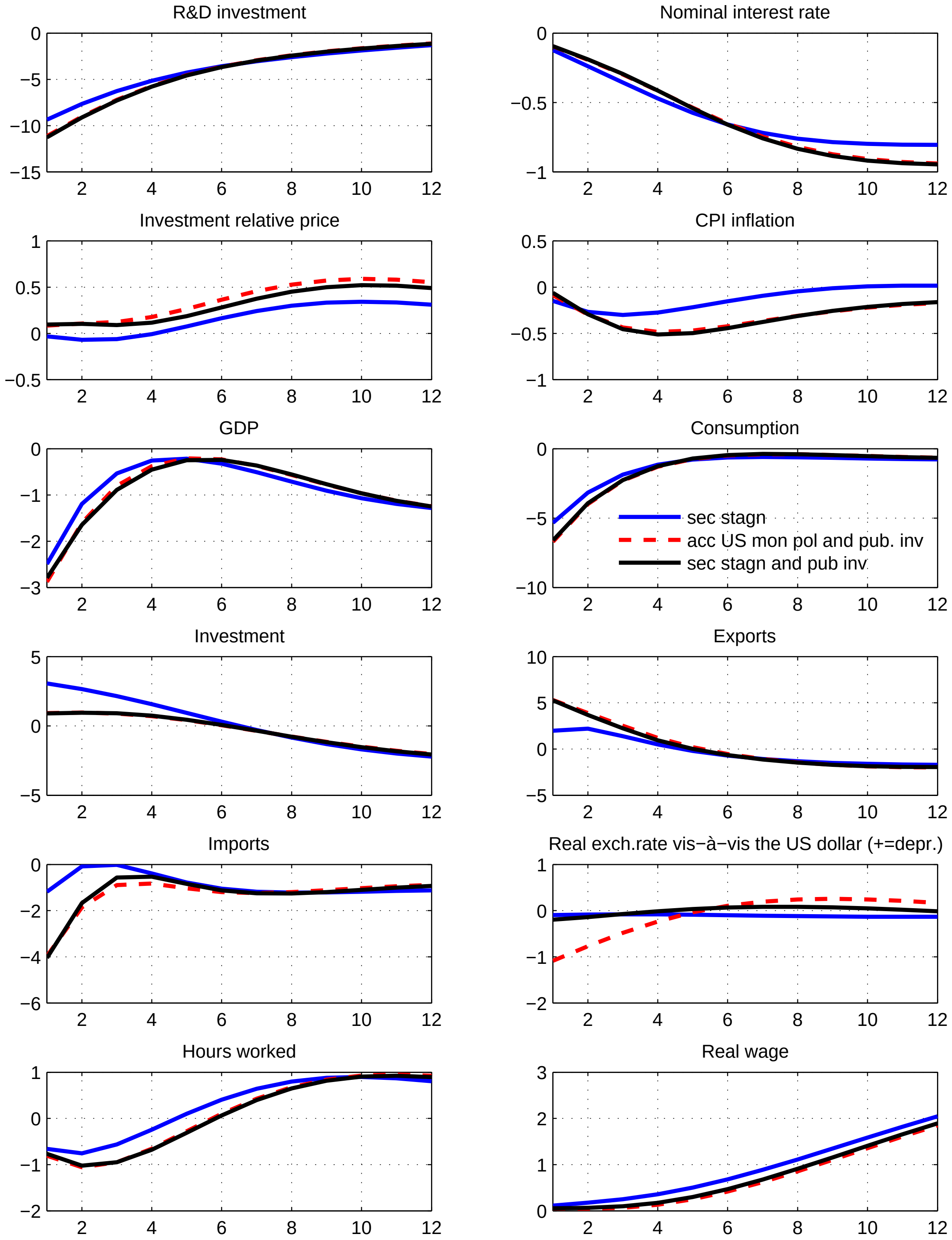
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

Figure 5: Secular stagnation, US public inv. and monetary stance. US variables



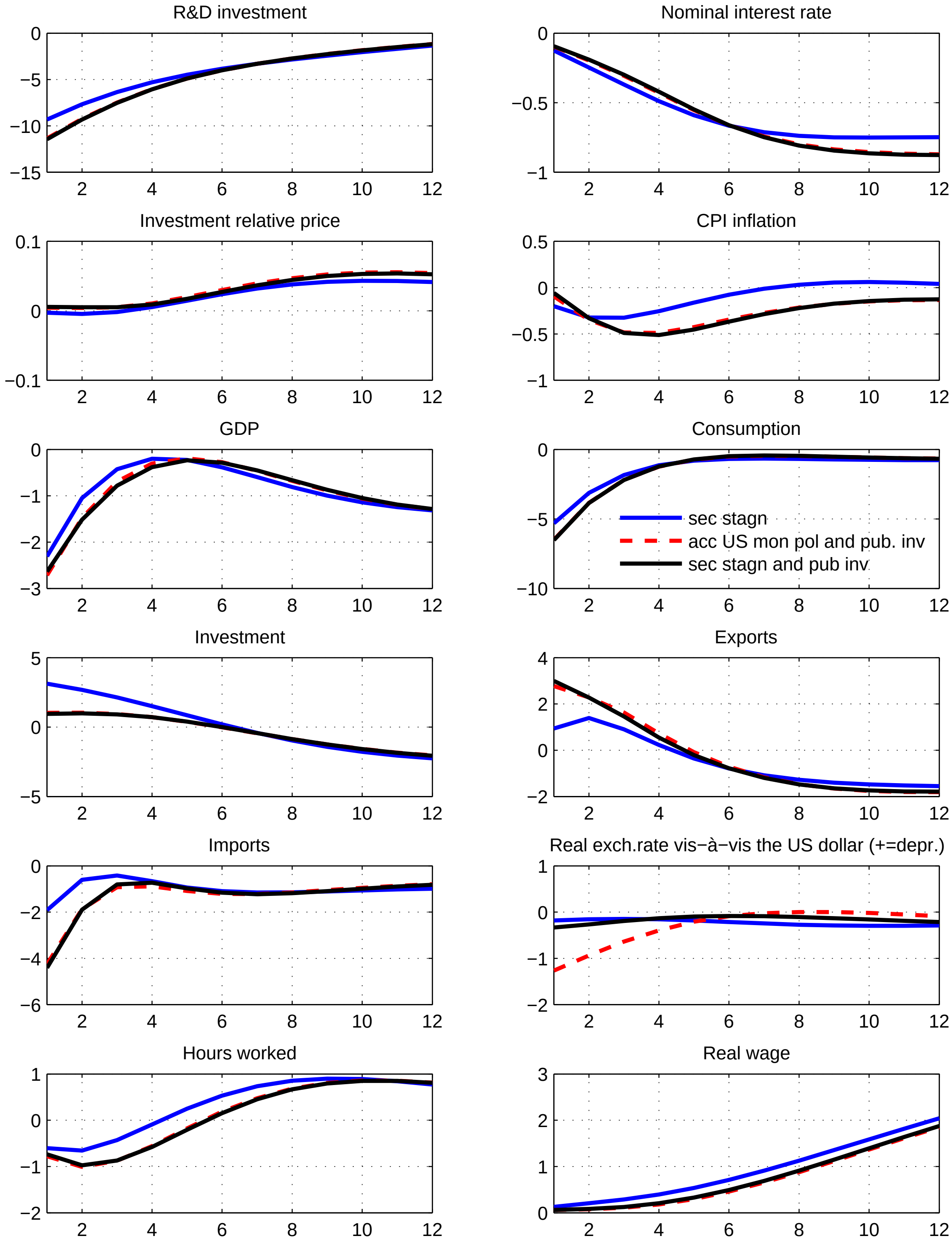
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



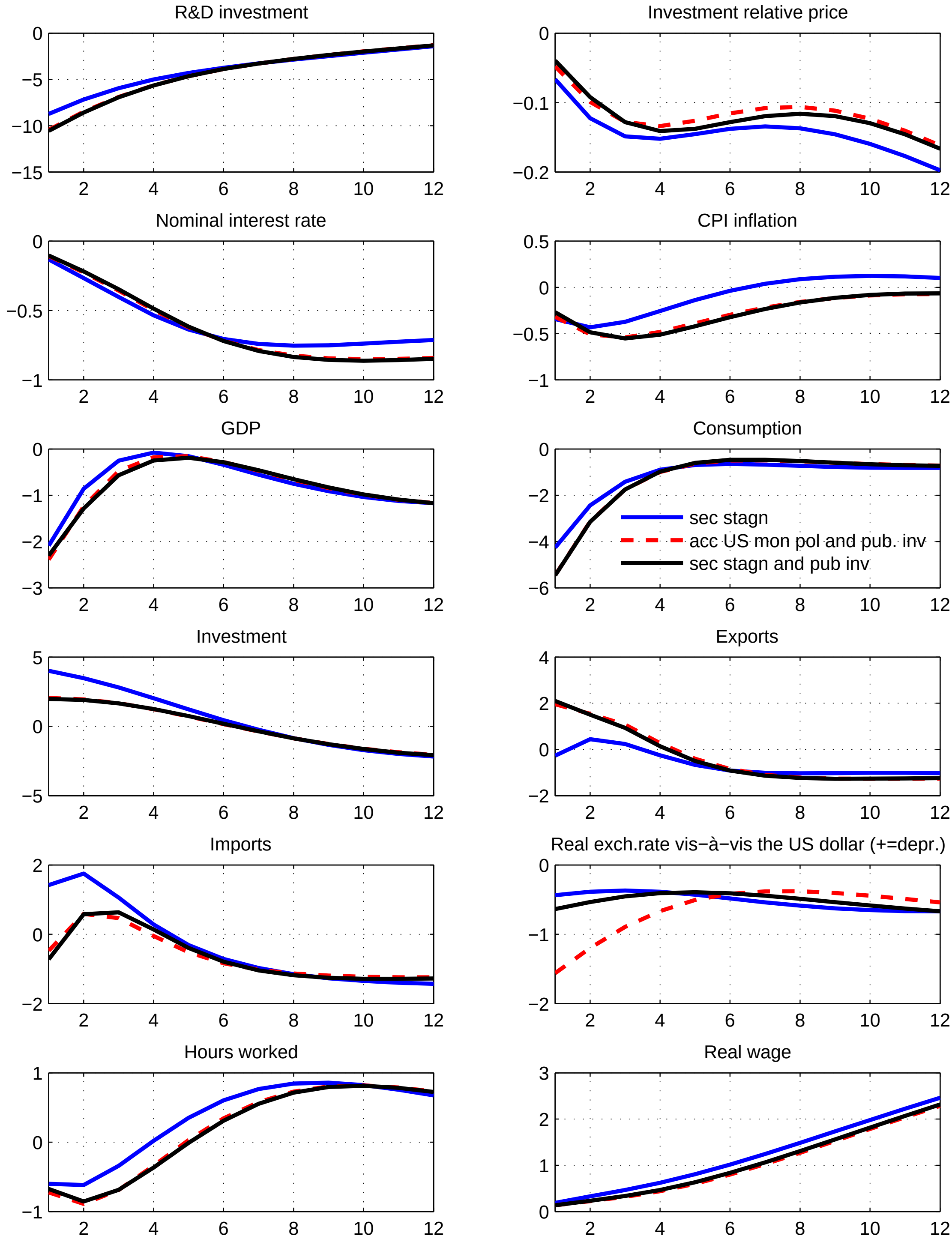
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



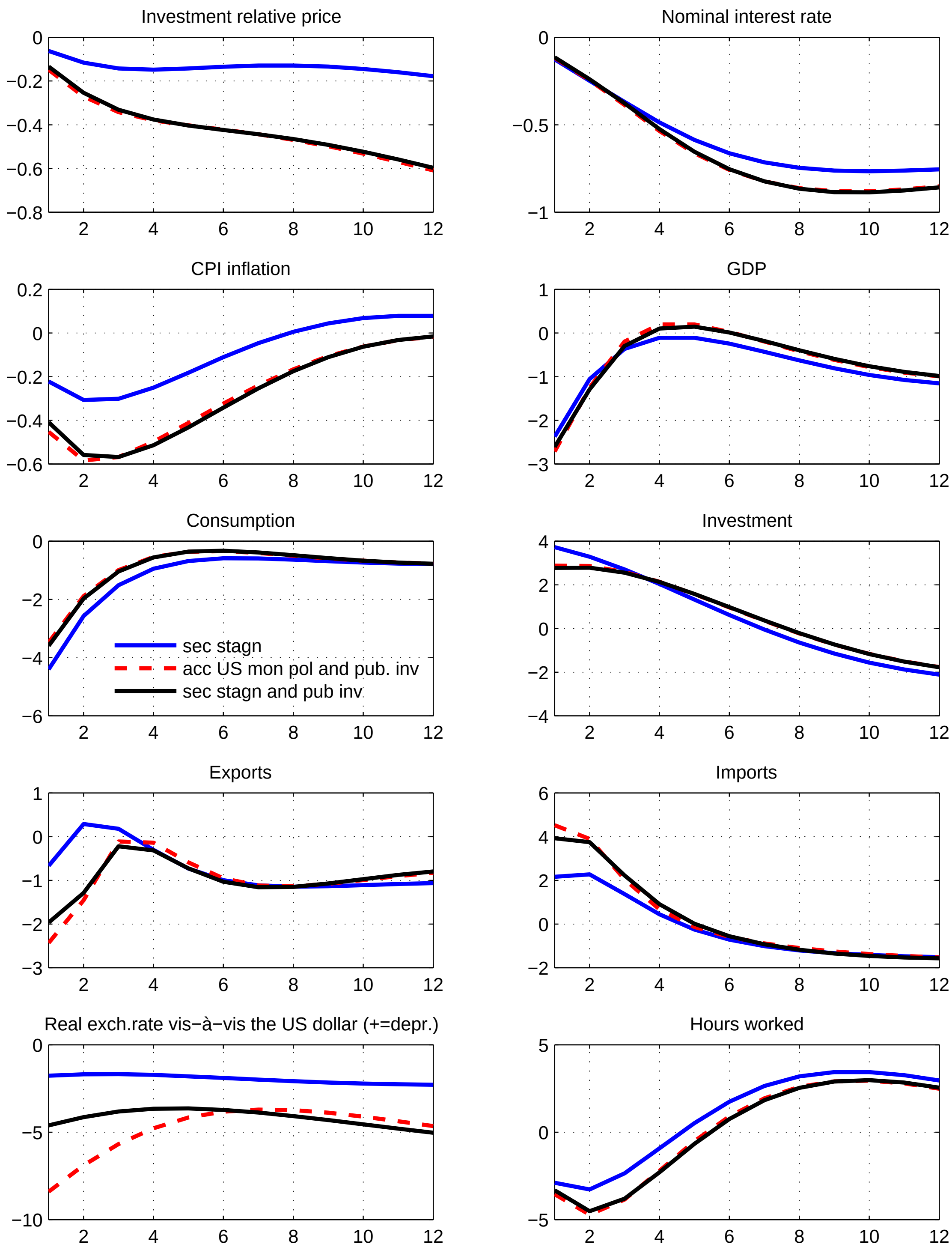
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



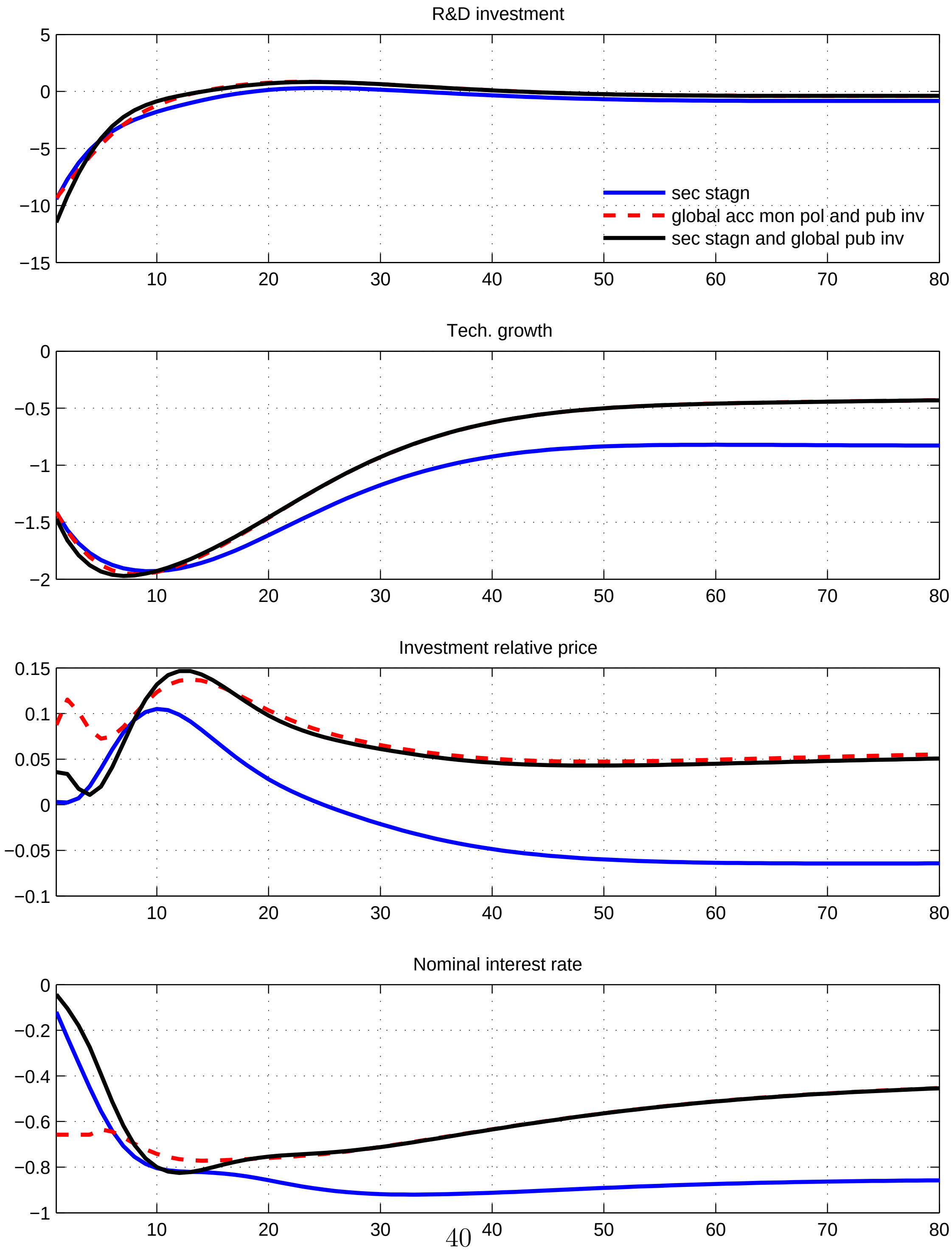
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



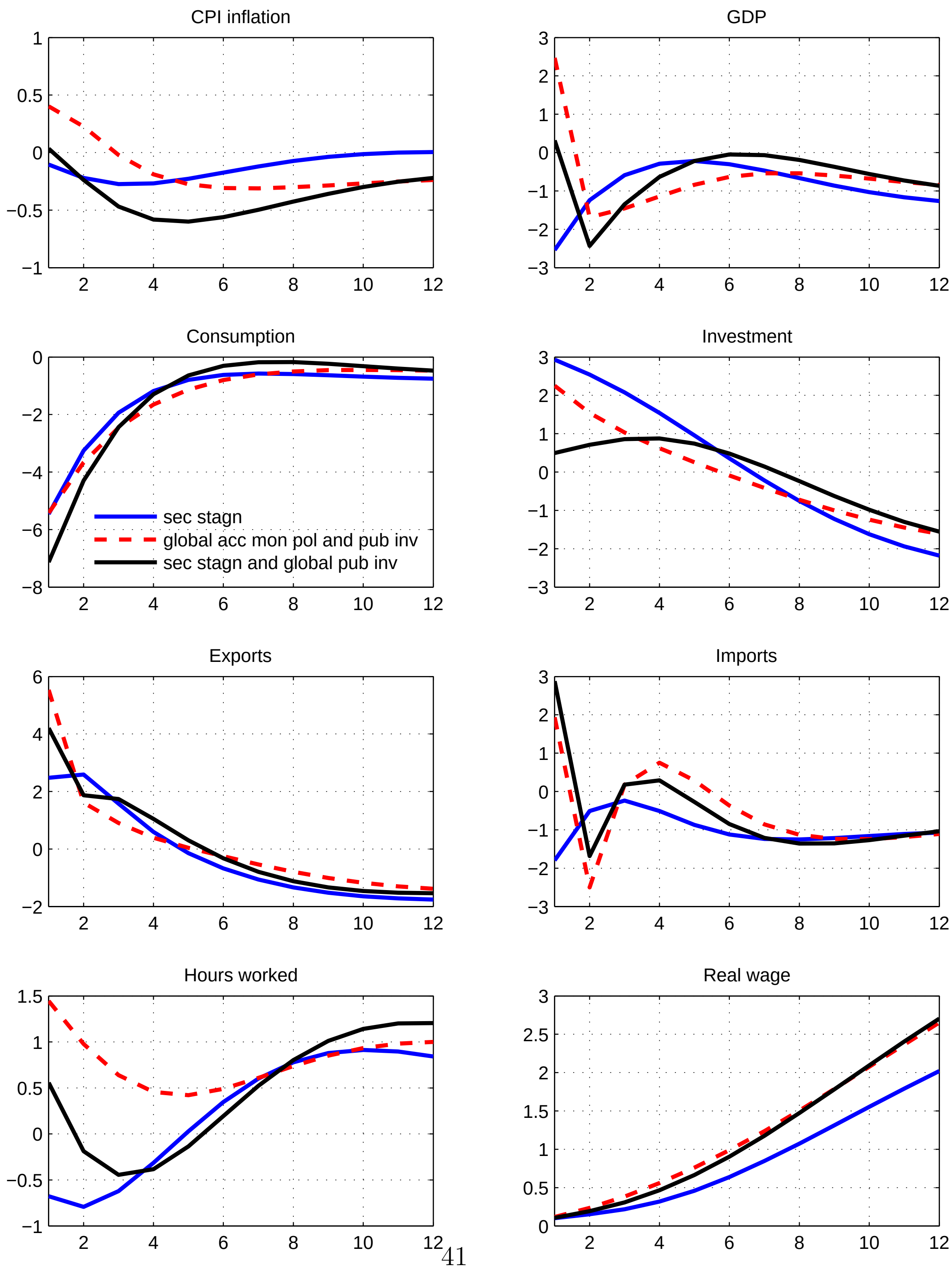
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



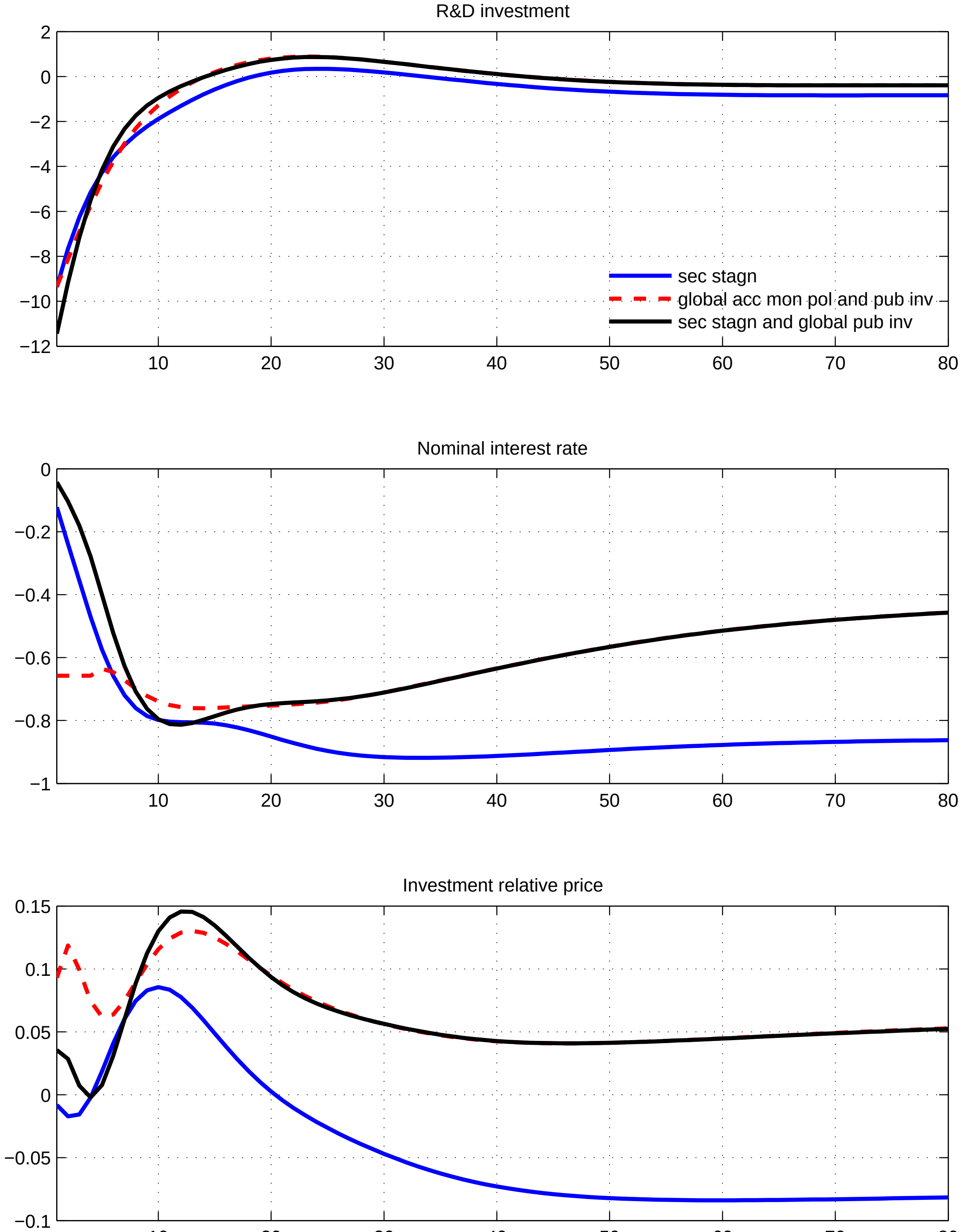
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



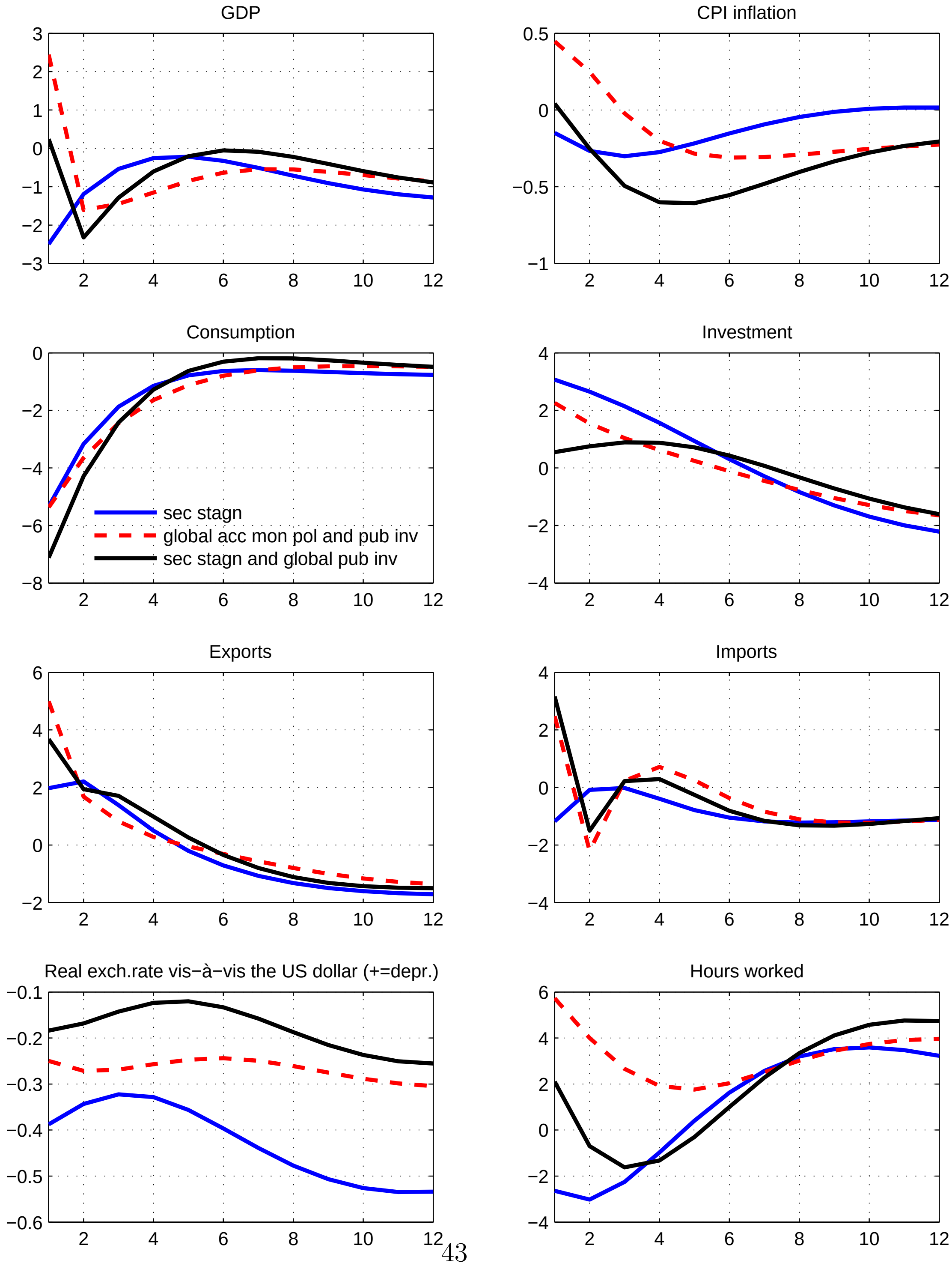
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



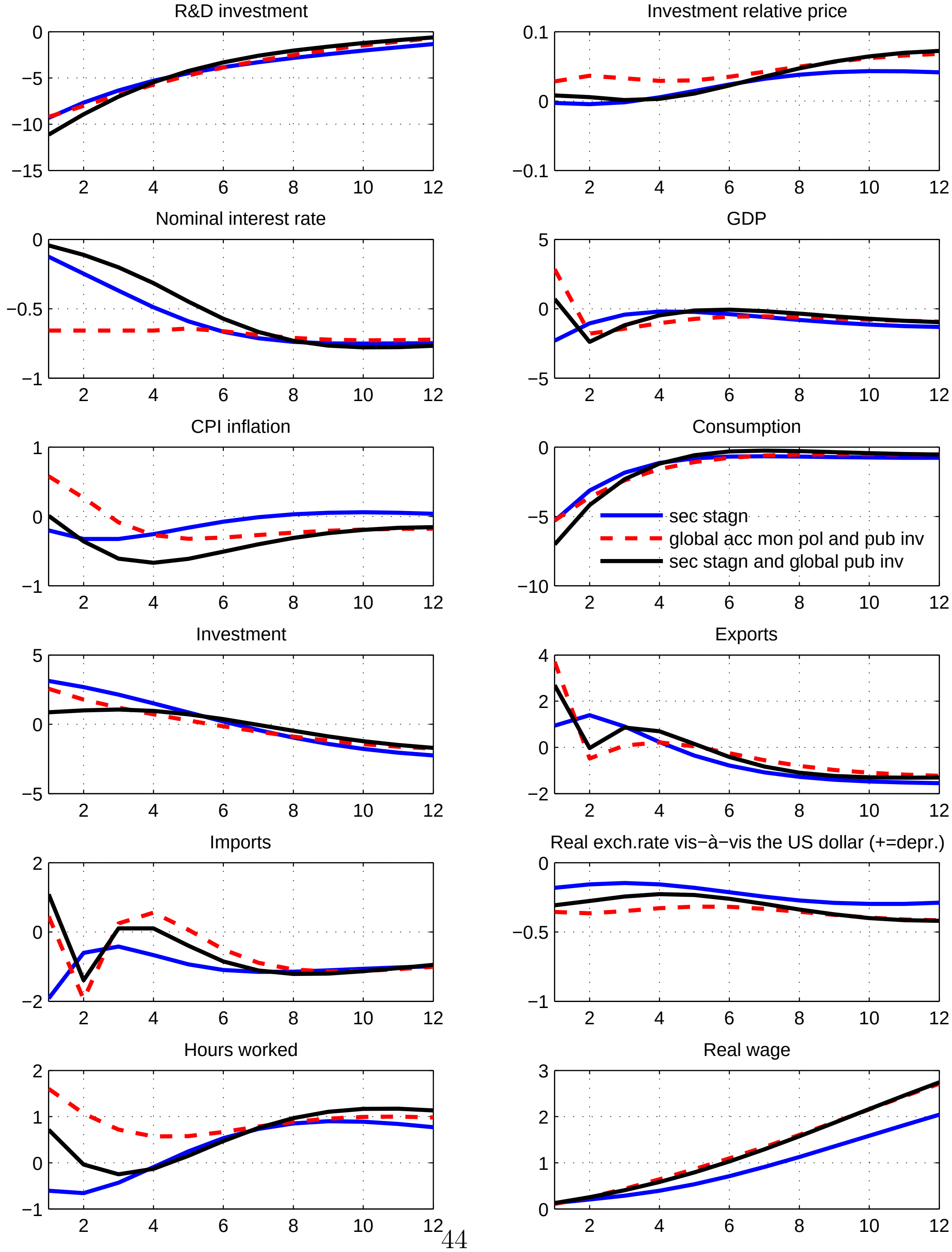
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



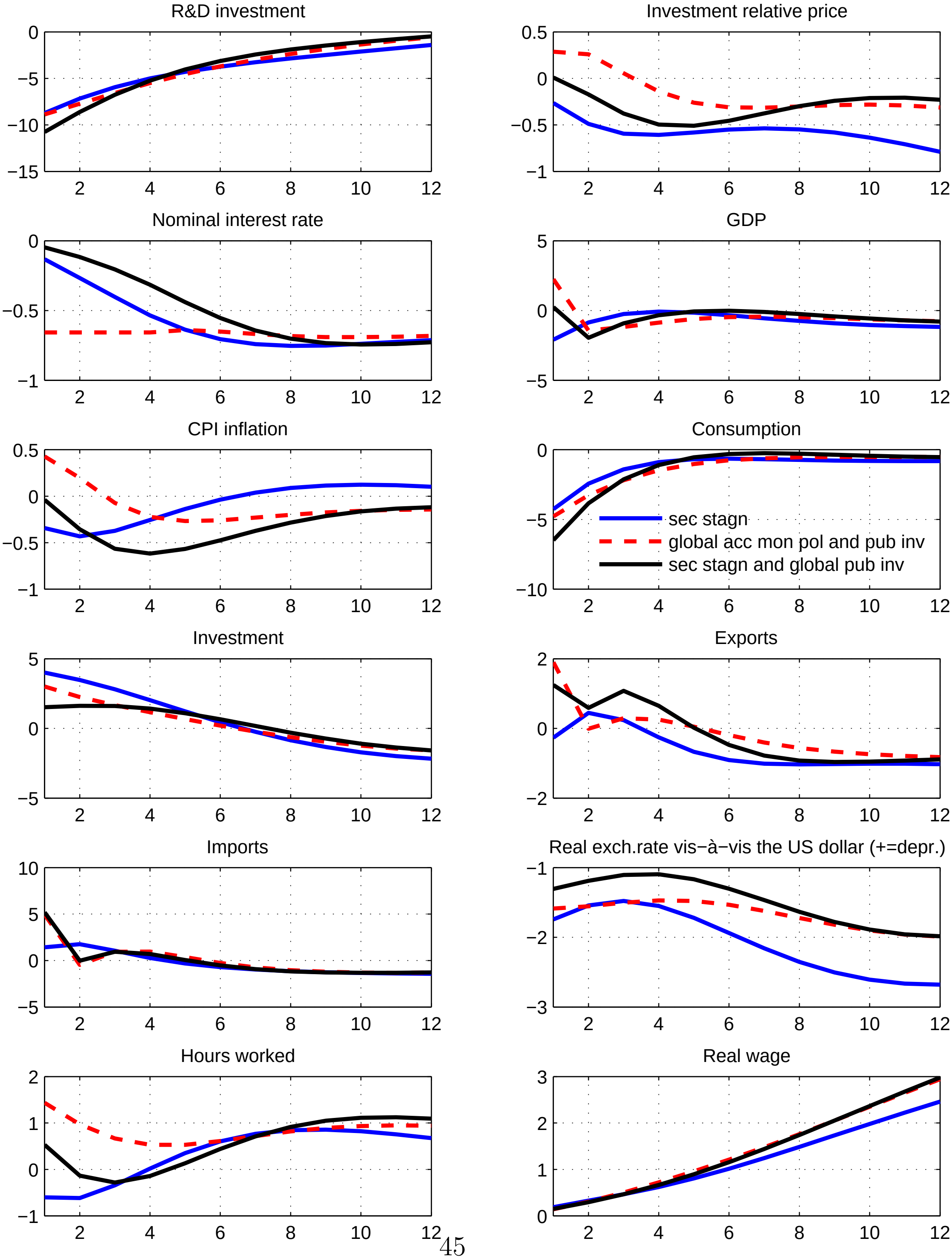
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



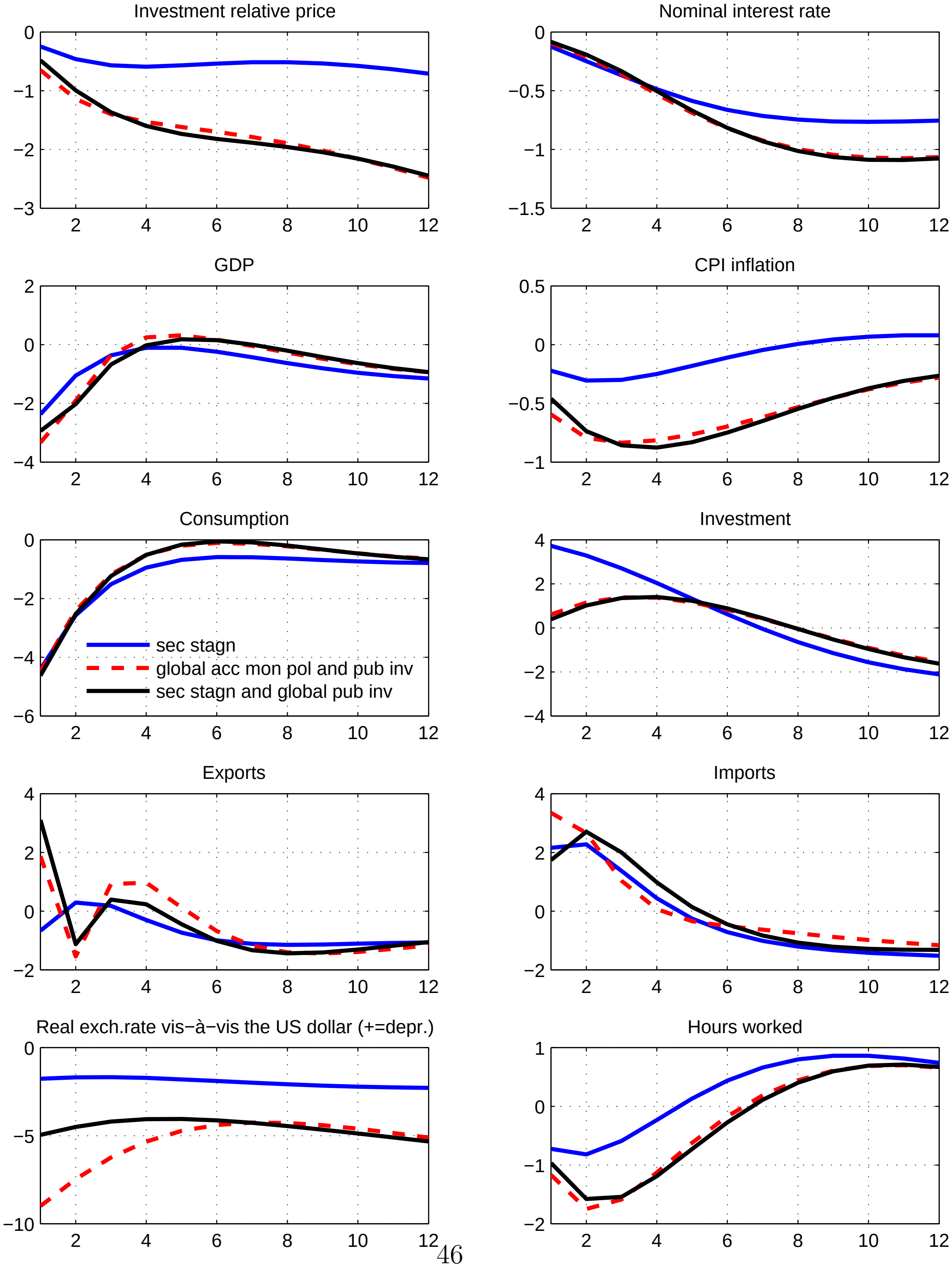
Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

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



Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.

Figure 16: Secular stagnation, global public inv. and monetary stance. RW variables



Note: horizontal axis: quarters; labor-augmenting technology, real GDP and its components' growth rates as annualized p.p. deviations from the before-shock growth rate; nominal interest rate and CPI inflation as annualized p.p. deviations from the before-shock corresponding values; real exchange rate, investment relative price, hours worked and real wage as % deviations from the before-shock corresponding values.