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Fiscal Austerity Measures: Spending Cuts vs. Tax Increases*

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Abstract

We formulate an overlapping generations model with skill heterogeneity and productive and non-productive government programs to study the macroeconomic and intergenerational welfare effects caused by risk premium shocks and government debt reductions. We demonstrate that in a small open economy with a high level of debt-to-GDP ratio a small increase in the risk premium leads to substantial output contraction and negative welfare effects. Next, we quantify the effects of reducing the debt-to-GDP ratio using a wide range of fiscal austerity measures. These reforms result in trade-offs between short-run contractions and long-run expansions in aggregate output. In addition, the spending-based austerity reform is dominated by the tax-based reform in terms of income in the short run, but becomes dominant in the long run. The welfare effects vary significantly across generations, depending on fiscal austerity measures, skills and working sector. The current old and middle age generations experience welfare losses while current young workers and future generations are beneficiaries of the reforms. A mixed reform results in the largest welfare effects.

JEL Classification: E21, E63, H55, J26, J45

Keywords: fiscal consolidation, welfare, distributional effects, overlapping generations, dynamic general equilibrium

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1 Introduction

Population aging and generous welfare systems have increased the national debt of many EU countries. This has raised many questions about the sustainability of current fiscal policies (e.g. see IMF (2010*b*)). The recent recession has contributed to this problem by decreasing GDP and tax revenues while increasing the need for fiscal spending. Nowhere is this more evident than in Greece, where fiscal deficits have precipitated repeated bail out packages from the EU. These developments present governments with various unpleasant options which either include large tax increases or substantial expenditure cuts or combinations of the two. The question as to which course of action is the most advisable is hotly debated among economists and policy makers.

There are a variety of factors and mechanisms that determine the macroeconomic outcomes of austerity measures. Among others, these factors include (i) the composition of the austerity measures, (ii) the size of the consolidation, (iii) the state of the macro economy at the time of the consolidation, and (iv) monetary and fiscal policy interactions (see Alesina and Perotti (1995), Giavazzi and Pagano (1996), Strauch and Hagen (2001), Guichard et al. (2007), Ardagna (2004), Bi and Leeper (2012), and Bi, Leeper and Leith (2011)). The literature does not provide a clear answer concerning which factors ultimately determine the success of a consolidation with Alesina and Ardagna (2010) arguing that the composition of the austerity measures matters for the success of the consolidations, while Ardagna (2004) argues that it does not.

Moreover, it has been documented in the previous literature that fiscal deficits and debt accumulation provide a means of redistributing income or tax distortions across generations and over time (e.g. see Barro (1979), Lucas and Stokey (1983), Cukierman and Meltzer (1989), Alesina and Tabellini (1990) and Tabellini (1991)). Fiscal programs including social security, unemployment insurance and public health insurance are emphasized as an important inter-generational redistribution mechanism in the public finance literature. To the best of our knowledge, such inter-generational welfare effects have not been analyzed quantitatively in the context of fiscal consolidations.

In this paper we provide an analytical framework of an economy which can be used to study the implications of various austerity measures on macroeconomic outcomes and welfare. We focus on quantifying the inter-generational and distributional effects of sizeable reductions of public debt. We construct an overlapping generations model based on Auerbach and Kotlikoff (1987) including skill heterogeneity, private and public sector production, a rich set of government expenditures including transfers, government consumption and government investment such as infrastructure. The model also includes a variety of tax instruments such as progressive income taxes, consumption taxes and the government's ability to issue debt.

The benchmark model is calibrated to Greece at the beginning of the 21st century. Greece is on the brink of bankruptcy as it faces a large public debt and permanent fiscal deficits due to low growth rates and insufficient tax collection. Greece agreed to subject itself to tough conditionality, negotiated and applied by the IMF and the EU. In exchange for external aid, Greece agreed to implement fiscal adjustments worth about 12.5 percent of 2009 GDP spread

over three years. This tightening is in addition to partly implemented reforms of about 6 percent of GDP. The goal is to reduce the deficit by 3 percent of GDP by 2014. The bulk of the measures will focus on increases of the VAT rate from 21 to 23 percent and cuts to public sector wages, pensions and employment numbers (Buiter and Rahbari (2010)).

We first demonstrate that a small increase in the interest rate due to a risk premium shock leads to large negative macroeconomic and welfare effects in a small open economy where governments rely heavily on borrowing from international capital markets. Specifically, we find that a small premium shock can plunge an economy with a high debt-to-GDP ratio into a severe recession that is difficult to overcome even when resorting to severe fiscal austerity measures. Our findings quantify the real costs of external risk premium shocks for countries with high levels of public debt like Greece.

Next, we quantify the effects of reducing the debt-to-GDP ratio from 105 percent of GDP to 85 percent of GDP in the long run using realistic fiscal austerity policies. In particular we consider: (i) tax-based austerity measures including increases in consumption or income taxes, (ii) spending-based austerity measures including cuts to public sector pensions and adjustments in public infrastructure investments, and (iii) a combination of tax increases and spending cuts. Our results are summarized as follows.

First, we find that the reforms result in immediate contractions but long-run expansions in aggregate output and consumption. The spending-based austerity measure, i.e. public investment in infrastructure, results in an increase in steady state output of over 5 percent, while the tax-based austerity measures lead to smaller increases in steady state output by around 4.3 percent. The analysis of the transition dynamics indicates trade-offs between short-run efficiency losses and long-run efficiency gains. There are sharp declines in output up to 6 percent in first 10 years and then strong recovery toward higher output in the long run.

Second, we calculate the size of the welfare gains or losses for all generations currently alive and born along the transition paths to the new steady state. At the aggregate level, the tax-based and spending-based austerity measures both results in welfare gains of almost 4.0 percent of pre-reform consumption in the new steady state. The transition analysis indicates trade-offs between welfare gains in the new steady state and welfare losses along the transition paths. Whether an individual gains or loses from the reform depends on the particular austerity policy, the working sector of the individual, as well as on the individual's remaining lifetime. More specifically, when infrastructure investments adjust to accommodate the debt reduction, the aggregate welfare effects are negative for about 10 transitional years after the reform and all generations born before the reform and the first generation born after the reform experience substantial welfare losses of up to 1.1 percent of pre-reform consumption. In contrast, when income taxes adjust to accommodate the debt reduction the aggregate welfare effects are positive. However, the generation-specific welfare effects are quite different. Retirees and workers who are close to their individual retirement age lose from the reform while middle-aged and young workers as well as future generations win.

Third, we find that the spending-based austerity reform is dominated by the tax-based reform in terms of the income and welfare effects in the short run. However, in the long run the

effects of the spending-based austerity reform become dominant as the economy fully recovers. In addition, we find that a mixed reform combining the tax-based and spending-based measures results in the largest income and welfare effects.

Contacts to the literature. Our paper connects to several branches of the literature. There is a growing macroeconomic literature analyzing the effects of debt financing and fiscal consolidation. Erceg and Linde (2012) analyze how the effects of fiscal consolidation differ depending on whether monetary policy is constrained by a currency union membership or by the zero lower bound on policy rates. Bi and Leeper (2012) study the implication of fiscal behavior for sovereign risk. Bi, Leeper and Leith (2011) explore whether or not fiscal consolidation is driven by tax increases or expenditure cuts. Forni, Gerali and Pisani (2010) quantify the macroeconomic implications of permanently reducing the public debt-to-GDP ratio in euro area countries. These papers build on New Keynesian type models and emphasize the interactions between fiscal and monetary policies. However, this literature, with the exception of Forni, Gerali and Pisani (2010), does not explicitly model the composition of government spending and tax revenues. They often neglect the trade-off between productive (education and public capital) vs. non-productive government spending (pensions and to some extent medical insurance) or the trade-off between income taxes vs. consumption taxes. Moreover, since these papers use a representative agent framework they often abstract from inter-generational and distributional effects of fiscal consolidations. Our paper is complementary to these papers as we incorporate agent heterogeneity and a variety of government activities. We are able to analyze not only the aggregate welfare effects but also distributional effects within and across cohorts.

There is a large literature analyzing the macroeconomic and distributional effects of fiscal policy. Baxter and King (1993) use an infinitely-lived, representative agent model to explore the general equilibrium effects of temporary and permanent changes in government spending and tax financing instruments. Heathcote (2005) investigates the effects of tax cuts in a heterogeneous agent model with infinitely-lived agents and incomplete markets. Kitao (2010) uses a large scale life-cycle model to quantify the effects of temporary tax cuts and rebate transfers in the U.S. Auerbach and Kotlikoff (1987), Imrohoroglu, Imrohoroglu and Jones (1995), Imrohoroglu and Kitao (2009), and Jung and Tran (2010) formulate overlapping generations models with heterogeneous agents and incomplete markets to analyze the distributional role of fiscal programs such as social security and health insurance. Glomm, Jung and Tran (2009) and Glomm et al. (2010) quantify the macroeconomic and welfare effects of public pension reforms in an overlapping generations model with productive governments. In this paper we focus on fiscal consolidation and austerity measures and the role of the risk premium in economies with large public debt.

There is a related literature investigating the growth effects of fiscal policy. Barro (1990), Glomm and Ravikumar (1994) and Glomm and Ravikumar (1997) analyze the implications of productive government expenditures for economic growth. The most recent studies incorporate government borrowing and study the growth implications of public investments. This literature argues that as government spending can itself be productive, the growth in public debt results in an expansion of production capacities. On the other hand, accumulating public debt crowds out

private investment as it extracts resources from the private sector. Governments therefore face a trade off: maintaining public debt sustainability while making sure that growth is promoted through productive investments (e.g. Moraga and Vidal (2004), Arai (2008), Yakita (2008) and Agénor and Yilmaz (2011)). Ireland (1994) and Bruce and Turnovsky (1999) study the conditions under which a tax cut alone or a tax cut combined with expenditure cuts can improve the fiscal balance in the long-run. Since these studies aim to obtain analytical results, the models are fairly simplified versions of the neoclassical growth model. Our paper emphasizes quantitative results using a more complex model that accounts for more details of fiscal policy.

The paper is structured as follows. The next section describes the model. In section 3 we calibrate the model to Greece and in section 4 we conduct policy experiments. Section 6 provides a discussion of the results and concludes. The appendix contains all tables and figures. A separate technical appendix, available upon request from the authors, contains the details for all the model solutions and the welfare calculations.

2 The model

We formulate an overlapping generations (OLG) model based on Auerbach and Kotlikoff (1987) containing descriptions of the private as well as the public sector and descriptions for public productions of infrastructure and private production of the final consumption good. Individuals are heterogeneous with respect to their skills, ages and working sectors. Imperfection in the credit market is modeled with a borrowing constraint. The economy is open with international capital mobility at the world interest rate, but international labor immobility.

2.1 Demographics and heterogeneity

The economy consist of a large number of individuals who live in an overlapping generations setting. We denote age as variable $j \in (1, \dots, J)$. The population grows exogenously at rate n . Every period new agents arrive and possibly live for J periods. Since we model working life beginning at age 20 and life ending at age 90, the maximum lifetime is 70 years and each period accounts for $\frac{70}{J}$ years. Individuals face age-dependent mortality shocks with a given survival

probability π_j . Let variable $\mu_j(\theta)$ denote the mass of age j agents with characteristic θ . We assume stable demographic patterns so that, similar to Huggett (1996), age j agents make up a constant fraction $\mu_{j,t}$ of the entire population at any point in time t . The relative size of each age cohort $\mu_{j,t} = \mu_{\theta, j,t}(\theta)$ is recursively defined as $\mu_{j,t} = \frac{\pi_j}{(1+n)} \mu_{j-1,t}$. It also is assume that

$$\sum_{j=1}^J \mu_{j,t}(\theta) = 1. \text{ Similarly, the cohort size of agents dying each period (conditional on}$$

survival up to the previous period) can be defined recursively as $v_{j,t} = \frac{1-\pi_j}{(1+n)} \mu_{j-1,t}$.

Individuals are heterogeneous with respect to age, skill, and working sector. Individuals are born with a specific skill type that determines their labor productivity. This skill type is fixed over the life time. Labor productivity measured as efficiency unit e_j varies over the life-cycle following

the typical hump-shaped pattern. We assume that newborn individuals are allocated to either work in the public sector or in the private sector. All individuals of a given age and

type are equally productive regardless of whether they work in the public or private sector.

We denote the skill type as $skill \in \{Low, High\}$ and the working sector as $sector \in \{P\ private, Government\}$. Here and in the rest of the paper the subscripts P and G denote private sector workers and public sector workers respectively. When we need to distinguish between the sectors we fix the sector variable to one of the sectors and use the following state vector notation $\theta_P = \{skill, sector = P\ private\}$ and $\theta_G = \{skill, sector = Government\}$. A typical agent is characterized by age, income type, and working sector, that can be summarized in state vector $\theta = \{skill, sector\}$.

2.2 Preferences

Within each period of their lives agents value a consumption good $c_{j,t}(\theta)$ and leisure $l_{j,t}(\theta)$ according to the utility function $u(c_{j,t}(\theta), l_{j,t}(\theta))$. This function has the standard properties of monotonicity and quasi-concavity. Individuals discount their future utility using the same discount factor β . A typical agent's lifetime utility is given by

$$\sum_{j=1}^J \beta^{j-1} u(c_{j,t}(\theta), l_{j,t}(\theta)).$$

2.3 Technologies

The final consumption good is produced from three inputs, a public good G_t , the private physical capital stock $K_{P,t}$, and effective labor (human capital) in the private sector $H_{P,t}$ according to the production function $Y_t = F_P(G_t, K_{P,t}, H_{P,t})$. This production function is homogenous of degree one in $K_{P,t}$ and $H_{P,t}$. The public good in the production function can be thought of as the stock of public infrastructure such as roads. This public good is made available to all firms at a zero price. Specifications of the technology similar to this one have been used by Barro (1990) and Turnovsky (1999) and others. Total factor productivity grows exogenously at rate g . Physical capital depreciates at rate δ each period.

The public good is produced from public capital $K_{G,t}$ and effective labor (human capital) of civil servants $H_{G,t}$ according to the production function $G_t = F_G(K_{G,t}, H_{G,t})$. This production function is characterized by the properties of monotonicity, concavity, and homogeneity of degree one. Public capital evolves according to $K_{G,t+1} = \frac{1}{(1+n)(1+g)} (I_{K,t} + (1 - \delta_G) K_{G,t})$, where public capital is detrended by the exogenous population growth rate n and the exogenous technological growth rate g . Public capital depreciates at rate δ_G in each period and $I_{K,t}$ is government investment in the public capital.

2.4 Factor markets

We assume a small open economy. Capital is free to move across borders. Domestic agents can borrow from the world capital market at interest rate r_t , which consists of two components: the fixed world interest rate \bar{r}_t and the country specific risk premium r_t^{risk}

$$r_t = f(\bar{r}_t, r_t^{risk}).$$

Note that we do not model the possibility of sovereign default. However, we are thinking of r_t^{risk} as a proxy for a country's sovereign risk.

Labor is internationally immobile, so that individuals cannot migrate. We assume a simple mechanism to allocate workers across public and private sectors. That is, individuals are assigned employment in either the public or private sector at the beginning of their life. We assume that for all cohorts in all time periods public sector wages exceed those in the private sector in order to mimic the more generous public sector compensation schemes that are commonly observed in many countries. This assumption also guarantees that all agents prefer public sector jobs to jobs in the private sector. In the labor market private firms can hire labor at the market wage rate. All agents will retire at age J_1 irrespective of the sector they are working in.

2.5 Government and fiscal policy

The government collects tax revenue to finance a number of fiscal programs. In the case of budget deficits, the government can borrow to cover its fiscal imbalances. The government budget constraint can be expressed as

$$B_{t+1} = \frac{1}{(1+g)(1+n)} \{ (1+r_t) B_t + Spend_t - Tax_t \}, \quad (1)$$

where B_t is one-period government bonds issued at time t ; r_t is the interest rate; $Spend_t$ is the total government spending; and Tax_t is the total tax revenue. Note that government bonds are detrended with the exogenous technological growth rate g and the exogenous population growth rate n . Newly issued bonds B_{t+1} are endogenously determined so that the government budget constraint is cleared every period.

Government expenditures. The government employs civil servants and uses physical capital to produce a public good G . The fraction of civil servants is fixed exogenously at N^G as a matter of government policy. The total wage bill of currently employed civil servants

is $Wage_{G,t} = \theta \sum_{j=1}^{J_1} w_{G,t} h_{j,t}(\theta_G) \mu_{j,t}(\theta_G)$. The wages of civil servants are set by the

government using a markup $\xi^W > 1$ over private sector wages so that $w_{G,t} = \xi^W \times w_{P,t}$. Private sector wages are determined by the market. In addition the government purchases physical capital K_G for public production. We assume that the government allocates a fixed fraction of GDP $\Delta_{K_G,t}$ for these purchases. The total government investment in this type of capital is $I_{K_G,t} = \Delta_{K_G,t} \times GDP$.

The government runs two separate pension programs, one for public sector workers and one for private sector workers. The pension scheme for public sector workers differs from the scheme for private sector workers in contribution rates and benefit payments. All workers of both sectors are required to participate in the pension program and consequently have to pay a social security tax $\tau_{SS,t}^P$ and $\tau_{SS,t}^G$. When workers retire they stop paying income

taxes and social security taxes and are eligible to draw pension benefits. Let Ψ_P and Ψ_G denote for the pension replacement rate in the private and public sector. We summarize the

payout formula to private sector retirees and for public sector retirees as $Pen_{j,t}(\theta_P) = \Psi_P \times \frac{1}{J_1} \sum_{j=1}^{J_1} w_{P,t-J_1+j} \times h_{j,t-J_1+j}(\theta_P)$ and $Pen_{j,t}(\theta_G) = \Psi_G \times \frac{1}{J_1} \sum_{j=1}^{J_1} w_{G,t-J_1+j} \times h_{j,t-J_1+j}(\theta_G)$,

respectively. Note that the payout formula is a function of the workers average earnings. The total pension payouts for private sector retirees and for public sector retirees are given by

$$Pen_{P,t} = \theta_P \sum_{j=J_1+1}^J Pen_{j,t}(\theta_P) \mu_{j,t}(\theta_P) \text{ and } Pen_{G,t} = \theta_G \sum_{j=J_1+1}^J Pen_{j,t}(\theta_G) \mu_{j,t}(\theta_G),$$

respectively.

The remainder of government expenditure including health care and welfare programs is government consumption C_G . Government consumption is unproductive. We assume that the government allocates a fixed fraction of GDP Δ_{C_G} for its consumption, i.e. $C_G = \Delta_{C_G} Y$. The total government spending at time t is given by the following identity:

$$Spend_t = \overbrace{I_{K_G,t} + Wage_{G,t}}^{\text{productive}} + \overbrace{Pen_{P,t} + Pen_{G,t} + C_{G,t}}^{\text{non-productive}}.$$

Government income. The government collects progressive income taxes from labor and capital income. Let $T(\phi)$ denote the progressive tax function that calculates the income tax of taxable income ϕ . The government also taxes consumption at rate τ_C . The government collects social security taxes from all workers in the private and public sector at rates of τ_{SS}^P and τ_{SS}^G , respectively. Accidental bequests are taxed at τ_{Beq} . The government's tax revenue at time t is given by

$$\begin{aligned} Tax_t = & \overbrace{\sum_{\theta \in \{\theta_P, \theta_G\}} \sum_{j=1}^{J_1} T(\phi_j(\theta))}^{\text{progressive income tax}} + \overbrace{\tau_{C,t} \sum_{\theta} \sum_{j=1}^J c_{j,t}(\theta) \mu_{j,t}(\theta)}^{\text{consumption tax}} \\ & + \overbrace{\tau_{SS,t}^P \sum_{\theta_P} \sum_{j=1}^{J_1} w_{P,t} h_{j,t}(\theta_P) \mu_{j,t}(\theta_P)}^{\text{soc. sec. tax from the private sector}} + \overbrace{\tau_{SS,t}^G \sum_{\theta_G} \sum_{j=1}^{J_1} w_{G,t} h_{j,t}(\theta_G) \mu_{j,t}(\theta_G)}^{\text{soc. sec. tax from the public sector}} \\ & + \overbrace{\tau_{Beq,t} \sum_{\theta} \sum_{j=1}^J a_{j,t}(\theta) v_{j,t}(\theta)}^{\text{tax on bequests}}. \end{aligned}$$

2.6 Competitive equilibrium

Households' problem. In general, households in the private and the government sector have similar maximization problems. Households decide their consumption of final goods and leisure $\{c_j, l_j\}_{j=1}^J$ as a function of their asset $a_{j,t}$, and skill type and working sector as summarized in state vector θ . The household problem can be recursively formulated as

$$V_t(a_{j,t}, \theta) = \max_{\{a\}} \{u(c_{j,t}, l_{j,t}) + \beta \pi_j V_{t+1}(a_{j+1,t+1}, \theta)\} \quad (2)$$

$j, t, c_{j,t}, l_{j,t}$
s.t.

$$\begin{aligned}
(1 + \tau_{C,t}) c_{j,t} + (1 + g) a_{j+1,t+1} &= Y_{j,t} \\
a_{j+1,t+1} &\geq 0, \text{ and} \\
0 &< l_{j,t} \leq 1,
\end{aligned}$$

where

$$Y_{j,t} = \begin{cases} R_t a_{j,t} + (1 - \tau_{SS,t}) (1 - l_{j,t}) e_j w_t + (1 - \tau_{Beq,t}) T_{Beq,t} - T(y_{j,t}) & \text{if } j \leq J_1 \\ R a_{j,t} + (1 - \tau_{Beq,t}) T_{Beq,t} + Pen_{j,t} - T(y_{j,t}) & \text{if } j > J_1 \end{cases}$$

is the household's after-tax income, $j = \{1, 2, \dots, J\}$ is age, $w_t = \{w_{P,t} \text{ or } w_{G,t}\}$ is the individual wage rate which is sector specific, R_t is the after tax interest rate, $T_{Beq,t}$ are transfers of accidental bequests that are taxed at rate $\tau_{Beq,t}$ and $y_{j,t}$ is taxable income at age j and time t , where $y_{j,t} = (1 - l_{j,t}) e_j w_t + r a_{j,t}$ if workers and $y_{j,t} = Pen_{j,t} + r a_{j,t}$ if retirees. Notice that e_j varies over the life-cycle following the typical hump-shaped pattern. Effective labor (or human capital) at each age is given by $h_{j,t} = (1 - l_{j,t}) e_j$. The social security tax rate $\tau_{SS,t} = \tau_{SS,t}^P$ or $\tau_{SS,t}^G$ as well as pension payments $Pen_{j,t} = Pen_{j,t}^P$ or $Pen_{j,t}^G$ are sector specific as well. $\tau_{SS,t} = \tau$ or τ as well as pension payments $Pen_{j,t} = Pen_{j,t}$ are sector specific as well.

Firms' problem. Firms choose physical capital $K_{P,t}$ and effective labor services $H_{P,t}$ to solve the following profit maximization problem

$$\max_{(H_{P,t}, K_{P,t})} \{F_P(G_t, K_{P,t}, H_{P,t}) - w_{P,t} H_{P,t} - q_{P,t} K_{P,t}\},$$

taking the rental rate of private capital $q_{P,t}$, the labor market wage rate $w_{P,t}$, and public capital G_t as given.

Definition of equilibrium. Given the distribution of skills, allocation of workers between public and private sectors, the government policy $\tau_{C,t}, \tau_{L,t}, \tau^P, \tau^G, \tau_{Beq,t}, \tau_{K,t}$ and

$$\Delta_{K_{G,t}}^{SS}, \Delta_{C_{G,t}}^{SS}, \xi^W, \Psi_{P,t}, \Psi_{G,t} \quad t=0$$

the exogenously given world interest rate $\{\bar{r}_t\}_{t=0}^\infty$, a competitive equilibrium is a collection of sequences of households' decisions $\{c_{j,t}, l_{j,t}, a_{j+1,t+1}\}_{j=1}^\infty$, sequences of aggregate stocks of private physical capital and private human capital $\{K_{P,t}, H_{P,t}\}_{t=0}^\infty$, sequences of aggregate stocks of public physical capital and public human capital $\{K_{G,t}, H_{G,t}\}_{t=0}^\infty$, sequences of factor prices $\{q_{P,t}, r_t, w_{P,t}, w_{G,t}\}_{t=0}^\infty$ such that

(i) households' allocations $\{c_{j,t}, l_{j,t}, a_{j+1,t+1}\}_{j=1}^J$ solves their recursive optimization prob-

lems (2) ,

(ii) rental rates, wages, and domestic interest rate are determined competitively by

$$\begin{aligned}
q_{P,t} &= \frac{\partial F_P(G_t, K_{P,t}, H_{P,t}, M_{P,t})}{\partial K_{P,t}}, \\
w_{P,t} &= \frac{\partial F_P(G_t, K_{P,t}, H_{P,t}, M_{P,t})}{\partial H_{P,t}}, \\
w_{G,t} &= \zeta^W w_{P,t}, \\
r_t &= f(\bar{r}_t, r_t^{risk}) = q_{P,t} - \delta_K, \text{ and } R_t = 1 + r_t,
\end{aligned}$$

iii) aggregate variables are given by

$$\begin{aligned}
A_t &= \theta \sum_{j=1}^J a_{j,t}(\theta) \mu_{j,t}(\theta) + \frac{\text{accidental bequests}}{\theta \sum_{j=1}^J a_{j,t}(\theta) v_{j,t}(\theta)}, \\
CA &= \frac{\text{domestic capital supply } K \text{ from HH}}{(A_t - B_t)} - \frac{\text{domestic capital demand from firms}}{\dot{K}_t},
\end{aligned}$$

where CA is the current account defined as the trade surplus plus interest from foreign assets and

$$\begin{aligned}
H_t^P &= \theta_P \sum_{j=1}^J \frac{h_{j,t}(\theta_P)}{(1 - l_{j,t}(\theta_P)) e_{j,t}(\theta_P) \mu_{j,t}(\theta_P)}, \\
H_t^G &= \theta_G \sum_{j=1}^J \frac{h_{j,t}(\theta_G)}{(1 - l_{j,t}(\theta_G)) e_{j,t}(\theta_G) \mu_{j,t}(\theta_G)}, \\
S_t &= \theta \sum_{j=1}^J a_{j+1,t+1}(\theta) \mu_{j,t}(\theta), \\
C_t &= \theta \sum_{j=1}^J c_{j,t}(\theta) \mu_{j,t}(\theta),
\end{aligned}$$

(iv) commodity markets clear¹

$$C_t + (1 + g) S_t + I_{K_G,t} + C_{G,t} = Y_t + (1 - \delta_P) K_t + (1 + n) (1 + g) B_t + Beq_b,$$

(v) taxed accidental bequests are returned in lump sum transfers to surviving agents

$$T_{Beq,t} = \frac{\theta_P \sum_{j=1}^J a_{j,t}(\theta_P) v_{j,t}(\theta_P) + \theta_G \sum_{j=1}^J a_{j,t}(\theta_G) v_{j,t}(\theta_G)}{\theta \sum_{j=1}^J \mu_{j,t}(\theta)},$$

(vi) and the government budget constraint (1) holds,

¹ Since the public good G is an input into private sector production of Y , the public sector wage bill is already contained in the measure of Y . For simplicity we do not take net exports into account when expressing policy parameters as percentage of GDP.

In addition, the aggregate S_t already incorporates the exogenous population growth rates via the population weight μ . We therefore only have to detrend with the exogenous technological growth rate g .

- (vii) the current account is balanced and foreign assets, FA , freely adjust so that the domestic interest rate is determined by $r_t = f(\bar{r}_t, r_t^{risk})$.

3 Parameterization and calibration

We parameterize the model and calibrate the baseline model to match the data from a small open economy. The recent fiscal developments in Europe have put several small European economies including Greece, Spain, Portugal and Italy on the brink of bankruptcy. Greece stands out as an example of public debt crisis followed by fiscal austerity policies. In 2010 Greece was induced to implement fiscal austerity measures to reduce deficits in order to receive international bail out packages by the international community. In our analysis, we choose Greece as a benchmark.

We calibrate the baseline model to match the data from Greece in the beginning of 21st century. We use a number of sources for the aggregate data from Greece.² We summarize the structural parameter values in table 1, policy parameter values in table 2, and matched data moments in tables 3 and 4. We solve the model numerically using an algorithm similar to Auerbach and Kotlikoff (1987). We next describe briefly the calibration of the model.

3.1 Demographics and heterogeneity

Agents become economically active at age 20 and die for sure at age 90. We calibrate the OLG model with $J = 14$ periods. Thus, each model period corresponds to 5 years. The annual population growth rate is $n = 0.2$ percent in 2006 according to UN Data Country Profiles. The survival probabilities are chosen so that the model matches the size of the various age groups in the population.

We distinguish 2 skill groups of workers according to their educational levels, so that $skill = \{Low, High\}$. *Low* stands for no education, primary education and some secondary education and *High* stands for complete secondary education and tertiary education. We calibrate the efficiency profiles $e_j(\theta)$ for each skill type using data from Tsakloglou and Cholezas (2005). The efficiency profiles exhibit the typical life cycle hump-shaped pattern. We scale down the skill/efficiency profiles of public sector workers to match their lower rate of weekly hours of labor.

3.2 Preferences

Preferences are represented by the utility function: $u(c, l) = \frac{(c^\gamma l^{1-\gamma})^{1-\sigma}}{1-\sigma}$, where c and l is consumption and leisure respectively, and $0 < \gamma < 1$ and $\sigma > 0$. Motivated by the real business cycle literature (e.g. Kydland and Prescott (1996)) we assume the elasticity between consumption and leisure is one. The parameter γ measures the relative weight of consumption versus leisure. The parameter σ is the coefficient of relative risk aversion.

² The sources include: OECD (2011a), OECD (2011b), HellasCountryFiche (2011), MOF (2011), Arghyrou and Tsoukalas (forthcoming), Koutsogeorgopoulou and Turner (2007), Monokroussos (2010), Rother, Schuknecht and Stark (2010), Buiter and Rahbari (2010), IMF (2006), BOG (2005), and Tsakloglou and Cholezas (2005).

The consumption preference parameter γ is chosen to match labor supply to be around 30 – 35 hours a week for agents in their prime working age from 25 to 55.³ Both, the time preference parameter $\beta = 1.03$ and the inverse of the inter-temporal elasticity of substitution $\sigma = 2.5$ are chosen to match the capital output ratio and the capital import rate. Consequently, in our model the resulting capital output ratio is 1.56.⁴

3.3 Technologies

The final goods production function is $F_P(G_t, K_{P,t}, H_{P,t}) = A_P G_t^{\alpha_1} K_{P,t}^{\alpha_2} H_{P,t}^{\alpha_3}$, where $\alpha_i \in (0, 1)$ for $i = 1, 2$, and 3 , $\alpha_2 + \alpha_3 = 1$, and $A_P > 0$. Total factor productivity A_P is normalized to one. The estimates for α_1 , the productivity parameter of the public good in the final goods production function, for the U.S. cluster around 0 when panel data techniques are used (e.g. Hulten and Schwab (1991) and Holtz-Eakin (1994)) and they cluster around 0.2 when GMM is used to estimate Euler equations (e.g. Lynde and Richmond (1993) and Ai and Cassou (1995)). Calderon and Servén (2003) estimate this parameter to be around 0.15 and 0.20. For a cross-section of low income countries Hulten (1996) obtains an estimate for α_1 of 0.10. We use $\alpha_1 = 0.09$. The capital share of GDP is very high in Greece so we chose $\alpha_2 = 0.35$. Parameter $\alpha_3 = 0.65$ together with the preference parameter for leisure $(1 - \gamma)$ determines average hours worked. Private capital depreciates at a rate of 10 percent per year, i.e. $\delta_K = 0.1$.

The production function for infrastructure is $F_G(K_{G,t}, H_{G,t}) = A_G K_{G,t}^\eta (\omega_h H_{G,t})^{(1-\eta)}$,

where $A_G > 0$ and $\eta \in (0, 1)$. The fraction of civil servants contributing to infrastructure production is $\omega_h \in (0, 1)$. The remaining civil servants produce government consumption that is not explicitly modeled. Total factor productivity $A_G = 4.25$ is chosen to match the size of the public goods sector. We have little information about the parameters of the infrastructure production technology. We view the choice of $\eta = 0.42$ and $\omega_h = 0.35$ as our benchmark and we perform sensitivity analysis on these parameters. Public capital K_G depreciates at 10 percent per year, i.e. $\delta_{K_G} = 0.1$. The exogenous rate of growth is 1 percent i.e. $g = 0.01$ (Akram et al. (2011)).

3.4 Factor markets

As in Bernoth, von Hagen and Schuknecht (2012) we use the interest rate spread as a proxy for the risk premium $r_t^{risk} = \frac{r_t - \bar{r}_t}{1 + \bar{r}_t}$. It is widely documented in the previous literature that a higher level of government debt is associated with a higher risk premium on government borrowing. We follow Bernoth, von Hagen and Schuknecht (2012) and define the risk premium as a function of the debt-to-GDP ratio

$$r_t^{risk} = \beta_0 + \beta_1 \frac{B_t}{Y_t} + \beta_2 \left(\frac{B_t}{Y_t} \right)^2.$$

³ See OECD.StatsExtract at <http://stats.oecd.org/Index.aspx?DataSetCode=ANHRS> factoring in an unemployment rate of 8 percent and <http://www.google.com/publicdata/directory>

⁴ It is clear that in a general equilibrium model every parameter affects all equilibrium variables. Here we associate parameters with those equilibrium variables that they affect the most quantitatively.

In order to estimate this polynomial we use OECD data from 2000 to 2008.⁵ We first construct an interest rate spread $\frac{(r_t - \bar{r}_t)}{1 + r_t}$, where r_t is the Greek long-run interest rate and \bar{r}_t is the German long-run interest rate which serves as a proxy for the risk free interest rate. We estimate the risk premium polynomial and obtain $\beta_0 = 0.2437$, $\beta_1 = -0.00538$ and $\beta_2 = 3.0E - 05$. These coefficients capture the long-run relationship between the risk premium and the debt-to-GDP ratio. The domestic interest rate is determined by

$$r_t = f(\bar{r}_t, r_t^{risk}) = \frac{\bar{r}_t + r_t^{risk}}{1 - \beta^{risk}}.$$

Based on OECD (2011a) and OECD (2011b) public sector employment as fraction of total employment is approximately 20 percent. We therefore set the fraction of public sector workers to $N^G = 0.2$. According to OECD (2011) the average retirement age is 62.4 for men and 60.9 for women. In our calibration we assume that all agents retire at age 60, or model period $J_1 = 8$.

3.5 Government and fiscal policy

All government policy parameters are summarized in table 2. According to Eurostat, the debt-to-GDP ratio was on average 105 percent in the ten year pre-crisis period. We target this ratio in our benchmark steady state model, i.e. $\frac{B}{Y} = 1.05$.

We assume that public sector workers earn on average up to 20 percent higher wages than private sector workers. We choose the pension replacement rates to match the size of the public and private sector pension programs as percent of GDP as well as the government revenue from payroll taxes paying for these pensions. We use replacement rates of $\Psi_P = 0.5$ and $\Psi_G = 0.87$ as well as payroll taxes of $\tau_{SS}^P = 12$ percent and $\tau_{SS}^G = 15$ percent in the private and public

sectors, respectively. Ad hoc subsidies to the public pension system in Greece amounted to about 3 percent of GDP in early 2000 (O'Donnell and Tinios (2003)). More recent information from the Greek Finance Ministry indicates that the state subsidizes pensions with over 13 billion euros every year, a figure that exceeds 5 percent of GDP.⁶ We assume that these subsidies are proportionally assigned to public and private sector pensions which results in pension deficits of 1 – 1.5 percent of GDP for public sector pensions and 3 – 4 percent of GDP for private sector pensions. We match these pension deficit figures as shown in table 4.

We calibrate purchases of private capital for public production ΔK_G to be 5 percent of GDP in order to match the size of the public good production as a share of GDP. Residual government consumption C_G is set to match the size of government. The government raises a progressive income tax on labor and dividend income⁷, a proportional consumption tax, and a proportional tax on bequests to finance investments into public capital K_G , public pension benefits, wage payments for public sector workers, service of its debt and government consumption C_G . According to Akram et al. (2011) total tax and non-tax revenues as fraction of GDP

⁵ Source: <http://stats.oecd.org>

⁶ http://www.ekathimerini.com/4dcgi/_w_articles_wsite1_1_06/03/2012_431420

⁷ http://www.taxexperts.eu/en/GUIDE/TaxExperts_Guide

are between 32 to 34 percent of GDP in 2010. The revenue streams from the various taxes match data on tax revenue from Akram et al. (2011) and OECD (2011*a*). Table 4 presents the details of the tax revenues that are matched in our benchmark model.

4 Policy experiments and results

We first explore the potential cost of a risk premium shock when the government is borrowing heavily from the international capital market in section 4.1. We then quantify the macroeconomic and inter-generational welfare effects of reducing public debt in section 4.2.

4.1 Underreporting public debt and risk premium effects

We first consider a risk premium shock due to the underreporting of public debt. It was reported that Greece repeatedly underreported its deficit prior to 2010. After the new Greek government took over in 2010 they revised the 2009 deficit from a previously estimated range of 3.7–5 percent to an alarming 12.7 percent of GDP. In April 2010, the reported 2009 deficit was further increased to 13.6 percent, and at the time of the final revised calculation by Eurostat it ended at 15.6 percent of GDP. These revisions are of course largely due to Greece not having correctly anticipated the magnitude of the crisis in its original projections for 2009. However, there has been speculation about earlier underreporting of the deficit but no exact estimates are available. In our experiment we assume a conservative 2 percent intentional underreporting of public debt to international lenders. This 2 percent underreporting is in accordance with a report by the European Commission (2010) for the three years 2006 – 2008 just prior to the crisis.⁸ The years 2006 to 2008 are years of relative macroeconomic stability before spikes in the debt-to-GDP ratio, the risk premium, and before precipitous drops in GDP.

We assume that the economy is initially in steady state with a “true” debt-to-GDP ratio of 105 percent. However, the government underreports its debt-to-GDP ratio as 103 percent to the international markets. This will lower the risk premium that is charged by the lenders. We calibrate the model to data prior to the crisis and solve for this initial steady state in period 0. In the initial steady state the government pays an interest rate of 4.6 percent rather than the 5 percent had it reported the true debt level of 105 percent of GDP. In period 1, we assume that the government reveals its “true” level of debt-to-GDP ratio of 105 percent. As news of the misreporting spreads, international lenders update the risk premium from period 1 onward. The domestic interest rate adjusts accordingly to reflect the true level of the risk premium.

Revising the debt-to-GDP ratio in this way simply introduces an unanticipated risk premium shock into our framework.⁹ The rise in the risk premium will require some adjustments in the government budget, since the increased risk premium represents an increase in the cost of debt services. We first assume that the government keeps debt-to-GDP constant at 105 percent. The government uses one of three financing options: (i) a change in the income tax rate for

⁸ Compare: <http://epp.eurostat.ec.europa.eu/>

⁹ Alternatively, we could consider an exogenous change in the country credit rating as a source of the risk premium shock. We could model it by shifting the estimated risk premium function.

higher income groups (τ_I); (ii) a change in the consumption tax rate (τ_C); or, (iii) a change in public capital investment in infrastructure (ΔK_G).

Macroeconomic aggregates. We report the steady state results in table 5 and the transition dynamics in figure 1. Note that all initial steady state levels are normalized to 100. We first start with the steady state results. The premium shock leads to an increase in the risk premium by about 22 percent, which corresponds to a rise in interest rate by 3.7 percent in the new steady state. This increase in the risk premium requires the government to adjust taxes or spending to finance additional borrowing cost. We find that the risk premium shock leads to a substantial contraction in output in the new steady state. The driving forces at work here are higher domestic interest rate and the distortions created by the government financing instruments.

The higher interest rate leads to a higher rental cost for physical capital in the domestic capital market. This subsequently leads to a contraction in the domestic production sector. As seen in row 4 of table 5, capital employed in the domestic production sector K_P drops by almost 3 percent. The demand for labor also falls, which leads to lower human capital H_P and a lower wage rate in the labor market. On the other hand, the higher interest rate has implications for the household sector. Since the return on savings is now higher, it induces households to save more. This leads to a large increase in household assets (K increases by almost 10 percent). The additional savings from households is therefore not used productively anymore but simply used to decrease capital imports (the current account decreases by almost 23 percent, that is Greece lowers its capital imports).

It appears that the distortions created by tax or spending adjustments are quite similar. The differences in output contractions are negligible across the three policies. Note that in our model the spending-based policy directly influences efficiency in the domestic production and the demand for production factors, while the tax-based policy leads to distortions on individuals' inter-temporal allocation and the supply of production factors. As the income tax rate on top earners is adjusted to balance the budget output drops by 1.7 percent and consumption by 0.4 percent (compare the first column in table 5). As the risk premium rises, the incentive to accumulate capital rises as well and thus the tax base increases. The increase in the interest income tax base is very large at almost 10 percent. This large increase allows a relatively modest increase in the income tax rate to top earners to balance the budget. The required increase in the income tax rate is 0.36 percent and the increase in the income tax revenue is 1.5 percent. Given the modest increases in income taxation the effects of the risk premium shock on output and consumption are relatively modest.

When the consumption tax is adjusted to balance the budget, the increase in the interest income tax base actually allows the consumption tax rate to fall by almost 3 percent (compare the second column in table 5). Since the consumption tax rate and revenue fall (by almost 3 percent each), aggregate consumption actually rises 0.1 percent, even though output drops by about 1.6 percent.

Finally, when public investment adjusts to balance the budget, the effects on output and consumption are of similar magnitudes as when the income tax rate adjusts (compare the third

column in table 5). In this case the additional tax revenue from the larger interest tax base allows for a 3 percent increase in infrastructure investments. However, this increase is not enough to offset the contraction in the private sector due to larger capital rental rates (note that physical capital used in domestic production K_P decreases by over 3 percent) so that ultimately output drops by about 1.5 percent. The negative effects on GDP are smaller when public investment in infrastructure adjusts to pay for the additional cost of borrowing.

Next, we explore the transitional dynamics following the policy reforms. In figure 1, we plot the transitions for output, savings, domestically used capital, employed human capital, and consumption after the risk premium adjusts to reflect the true 105 percent debt-to-GDP ratio. We show the transition for the case in which the income tax rate, the consumption tax rate and the investment in infrastructure adjust to balance the budget after the misreporting of the deficit is revealed.

The increase in the domestic interest rate results in two opposing effects on savings. First, the new high rate of return encourages households to increase savings; on the other hand, the negative income effect decreases savings. It is clear that the price effect is dominant and persistent, so that savings increases gradually to the new steady state of about 110 percent of the pre-shock level. In our small open economy model, higher domestic savings do not immediately result in an increase in capital accumulation. In fact, the capital stock employed in the domestic production falls by 2 percent immediately after the increase in the risk premium, and then gradually decreases to about 3 percent below the pre-shock level. The immediate fall in capital stock in production is driven mainly by the lower demand for capital in response to the high rental cost of capital and the low level of human capital. In the context of a small open economy, the high savings and low demand for capital in the domestic production induces capital exports (that is a lowering of very high capital imports from the benchmark level).

Interestingly, there are significant differences in the speed of convergences along transitions. Output drops more during the early stage of the transition and then becomes quite flat when the investment in public infrastructure is adjusted to balance the budget. Meanwhile, the output gradually decreases to a the new steady state level when taxes adjust. Yet, the contraction in output happens faster over the transition but are smaller in the new steady state compared to the case where the public investment is adjusted.

Welfare. We next conduct welfare analysis. For every agent type we calculate what fixed percentage of consumption, as a fraction of initial steady state GDP, has to be added or subtracted in each period to make her indifferent between the original steady state and the new steady state with the lower debt-to-GDP ratio. We also calculate compensating consumption as a percent of pre-reform consumption levels per agents type. This allows us to investigate the size of the welfare loss for each agent individually. Note that negative values indicate welfare gains, while positive numbers indicate welfare losses.

We start with the steady state effects on welfare outcomes. The bottom part of table 5 contains compensating consumption units as a fraction of pre-reform GDP with income tax (τ^l) in column 2, consumption tax (τ^c) in column 3, and public investment in column (Δ^G) in

column 4.

The aggregate welfare effects are relatively small, except for the case when the income tax is adjusted. With the adverse risk premium shock, one would expect only negative welfare effects in the aggregate and for each of the demographic groups. This expectation is not borne out with the steady state results. The welfare effects vary significantly across skill types and working sectors. High skill workers experience welfare losses, while low skill workers experience welfare gains in the new steady state. When the consumption tax rate adjusts, the aggregate welfare effects are very small, but positive. This outcome is mainly driven by the fact that welfare gains for low skill workers in the private sector dominate welfare losses for high skill workers.

The welfare effects along the transition are more interesting. Figure 2 illustrates the welfare costs/benefits associated with this adverse shock and the associated necessary adjustment of the income tax along the transitions. As seen in panel 1 of figure 2, at the aggregate level welfare losses from this adverse shock rise monotonically during the transition to 0.2 percent of aggregate consumption in the new steady state. We track the welfare effects across agent types and generations. The bottom 2 panels of figure 2 illustrate the welfare losses/gains for the different worker types over time. The current retirees suffer least or experience welfare gains from the risk premium shock. The reason is that the increase in domestic interest rate generates a positive wealth effect for those agents who rely on savings incomes. On the other hand, the current working population and future generations will experience welfare losses. This welfare effects result directly from the sharp contractions in the domestic production along the transition. Moreover, we find that the welfare effects vary significantly across skill types and working sectors. Over time the welfare losses for the high skill workers converge to about 0.4 and 0.8 percent of consumption for private and public sector workers respectively. Simultaneously the welfare losses for the low skill types remain below 0.2 percent for public sector workers and are very small but positive for low income private sector workers. These workers are poor enough so that they are not hit by higher income taxes.

Alternative austerity measures in response to a risk premium shock. We next consider alternative fiscal policies to finance the cost of the premium shock. After the onset of the fiscal crises there was a general sense that the public sector was too large and that there are many potential reforms that could restore fiscal order. Typical public sector reforms include cuts to pensions of public sector workers (i.e. Imrohoroglu and Kitao (2009), Glomm, Jung and Tran (2009) and Glomm et al. (2010)), cuts to wages of public sector workers, or hiring freezes or even layoff as branches of governments are consolidated (Buiter and Rahbari (2010)). We therefore calculate the steady state results of the following reforms: in order to pay for the higher risk premium the government (i) cuts the size of the public sector workforce N_G by 15 percent, (ii) public sector wages w_G by 15 percent, or (iii) the reimbursement rate of public sector pensions (measured by parameter Ψ_G) by 15 percent. In all three cases, the government also adjusts either the income tax rate of the three highest income groups (τ_I) or public capital investments (Δ_{K_G}) in order to balance the budget constraint. The steady state implications

of these reforms are illustrated in table 6. In column [2] of table 6 for example, public sector employment (N_G) is cut 15 percent and public capital investments into infrastructure (Δ_{K_G}) is adjusted to balance the government budget.

As we can see the surprise increase in the risk premium almost always leads to a contraction with one exception in column [2] in table 6. In this case the government cuts the size of the entire public sector and lets infrastructure investments (Δ_{K_G}) adjust to balance the government budget constraint. The government uses the savings from a smaller public wage bill as well as the additional tax revenue from interest income and invests it into public capital (i.e. infrastructure). In essence the government replaces fairly unproductive labor in the public sector with more productive (public) capital. In addition, the private sector does not experience the large drop in physical capital in its domestic production sector because more human capital is available (note that as the public sector human capital is cut, it moves into the private sector so that human capital in the private sector H_P increases). This is the only case where the government is able to generate growth beyond the benchmark results and without reducing its debt. In all other cases, the high debt burden in combination with high interest rates prevents the government from generating higher output.

One of the worst, if not the worst, policy reform in terms of steady state output and consumption is to cut public sector wages (w_G) and adjusting the income tax (τ_I), column [3] in table 6. The income tax will have to increase by 2.3 percent, which leads to a drop in capital employed in the private sector so that output and aggregate consumption both drop by about 2 percent.

In general the welfare results show a similar outcome across these policies. Welfare gains across all groups are only possible in the case where GDP grows sufficiently (i.e. column [2] of table 6). The worst scenario in terms of welfare is again realized by the policy that decreases public sector wages and lets income taxes adjust to balance the budget constraint (i.e. column [3] of table 6).

We have thus demonstrated that just a small risk premium shock can plunge an economy with a high debt-to-GDP ratio into a recession that is difficult to overcome even when resorting to relatively severe fiscal austerity. This result highlights the large real costs of being exposed to external shocks for countries who currently have very high levels of public debt-to-GDP like Greece and other Southern European countries. Indeed, if Greece were to maintain its current public debt, it would be very difficult to find policies that would allow Greece to grow out of its fiscal woes. We next study the macroeconomic and welfare implications of reducing public debt.

4.2 Reducing public debt

The experiments in this section are motivated not only by theoretical curiosity, but also by recent fiscal developments in Greece. Over a concern for non sustainability of fiscal policy more drastic reform measures with the goal to reduce the debt burden were discussed and implemented. The Greek government agreed to implement significant fiscal adjustments worth

about 12.5 percent of 2009 GDP spread over the next three years in order to receive international bailout packages (compare IMF (2010a)).

In our experiment we again start from the initial steady state in period 0. In period 1 the government implements fiscal austerity measures to reduce its debt-to-GDP ratio to 85 percent in the long run. In particular we consider a scenario in which the government implements the reduction of its debt-to-GDP ratio over a 15 year period. After the first 5 years it reduces its debt-to-GDP ratio to 100 percent, after 10 years to 95 percent, and after 15 years to the target rate of 85 percent in the long run. As before we impose that the government has three sets of policy instruments to implement this debt reduction: (i) tax-based measures, (ii) spending-based measures, and (iii) a combination of both.

Macroeconomic aggregates. We report the steady state results in table 7 and the transition dynamics in figure 3. Note that all initial steady state levels are normalized to 100. We first describe the long run effects.

Reducing the long run debt-to-GDP ratio to 85 percent leads to a significant decrease in the risk premium by about 60 percent with an associated decrease in the interest rate by 11 percent in the new steady state. The rental rate of capital is now lowered because of the smaller risk premium. The permanent reduction in the debt-to-GDP ratio induces a significant expansion in economic activities. In particular, these tax revenue reductions induce an modest increase in labor supply and a very large increase in savings. Interestingly, the large increase in domestic asset accumulation is not enough to satisfy the capital demand in the economy so that the capital accounts expand and more “cheap” capital is imported.

Specifically, capital employed in production (K_P) increases by at least 8 percent in all cases, columns [1-3]. The biggest increase in capital employed occurs when infrastructure investment adjusts (i.e. a 10.1 percent increase as seen in column [3] of table 7). This is due to the complementary relationship between capital and infrastructure. Since capital and labor are also complements there is an increase in the demand for effective labor. The magnitude of the increase in human capital employed in the economy depends upon the size of the changes in the policy instruments. In general the increase in human capital employed in the private sector H_P is quite modest, falling between 0.9 and 1.7 percent. This in turn increases the real wage by up to 3.6 percent.

As both capital input and labor inputs rise in all three cases, output increases as well across the board. It is clear from table 7 that these policy experiments increase both output and consumption in the long run regardless of which policy instrument adjusts. The output gains are between 3.6 percent and 5.3 percent with the smallest gains being realized when the income tax rate adjusts and the largest gains being realized when infrastructure investment adjusts. The consumption gains are between 2.5 percent and 4 percent, with the smallest gains realized in the case of income tax rate adjustment, and the largest in the case of consumption tax adjustments.

As a direct consequence of the debt reduction the government does not have to finance the large debt services anymore and more funds can be released to reduce taxes or increase spending.

As can be seen from table 7 the consumption tax rate in column [2] falls by 6.2 percent and the public investment in infrastructure in column [3] increases by almost 12 percent. In the second case, column [2], we find that the new consumption tax rate is lower in the new steady state. This has to do with lower debt service payments as well as with a broadening of the consumption tax base as aggregate consumption increases by almost 4 percent. All in all the consumption tax revenue is decreasing though which again reflects the lower debt service in the new steady state. When public capital investments into infrastructure Δ_{K_G} adjust to accommodate the lower debt level and the resulting lower debt service we see that government investments into public capital as percent of GDP increases by almost 12.0 percent.

Notice that debt reduction does not always lead to a lower tax rate in our general equilibrium model. As can be seen from column [1] in table 7, when the income tax rate adjusts to balance the budget it increases by 2.8 percent in the new steady state. This outcome is driven by two factors. First, the lost interest revenue due to the lower interest rate shrinks the tax base on interest income. Interest income on asset holdings drop by about 18 percent, with a drop in the overall income tax base of up to 3.7 percent. Second, since the economy grows by over 3.6 percent, so do the government spending programs that are indexed to GDP such as the public sector wage bill and public pensions (Note: only infrastructure investments Δ_{K_G} are pegged at pre-reform levels). All in all this leads to a slight increase in the marginal income tax rate in the long run.

The temporary tax increases result in strong disincentive effects on the households' labor supply and savings decisions over transitions (see figure 3). Hours of work and aggregate human capital decreases during the years of high taxes. Aggregate human capital subsequently decreases about 2 percent in the first period after the shock. On impact, savings drops by about 6 percent before converging to about a 7 – 8 percent increase compared to pre-reform levels. As seen in panel 1 of figure 3, following the immediate decline in inputs in the early transition years, output drops as well. This drop in output occurs regardless of the fiscal policy instrument that is used to balance the budget. Such contraction in domestic production implies a recession. The recession is short-lived since output rises quickly to over 5.5 percent above pre-reform levels.

More importantly, the transition dynamics highlights trade-offs between short-run losses and long-run gains. These reforms result in immediate contractions but long-run expansions in aggregate output. Comparing the transition path generated via tax-based measures to the path generated by spending-based measures we also see that the economy reacts strongest (in terms of output) to adjustments in public investments into public capital in short run. This result is contrary to recent findings in the literature (see Alesina, Favero and Giavazzi (2012)) that point out that adjustments based on spending cuts are much less costly in terms of lost output than losses triggered by increases in the tax rate. Note that we only focus on productive government spending. Note that the underlying mechanisms are different in our framework. The tax-based reform reduces the fiscal distortions on individuals' intertemporal allocation and the supply of production factors, while the spending-based reform works through improving production efficiency and the demand for factors of production. The latter turns out to be

stronger in enhancing production activities in the long run. This result highlights that the type of fiscal austerity measure that gets implemented matters for domestic production in an open economy setting.

Welfare. The long run welfare effects are reported at the bottom of table 7. Reducing the debt-to-GDP ratio results in positive welfare outcomes, not just in the aggregate, but for each one of the groups in the new steady state. The positive welfare outcomes are driven by expansions in steady state income and consumption after removing the fiscal distortions caused by excessive debt burdens. The welfare effects vary substantially across different policy measures and agent types. The largest welfare gain appears when the consumption tax is adjusted in reaction to the cuts in the debt-to-GDP ratio. It is of interest to note that the rich reap bigger welfare gains than the poor measured in percent of their own lifetime consumption and that private sector workers reap bigger gains than public sector workers. This is true regardless which of the three policy instruments is used to balance the government budget.

We report the welfare effects during the transition of a tax-based reform in figure 4 and a spending-based reform in figure 5. Panel 1 of figure 4 illustrates the welfare gains associated with the transitions, when the income tax adjusts to accommodate the decrease of debt. The aggregate welfare gains grow immediately and monotonically to a little over 1 percent of GDP. These long-run welfare gains are unequally shared among the different groups (see Panel 2 and 3 of figure 4). Welfare gains for high skill workers are generally larger than for low skill workers and gains to the public sector workers are larger than to private sector workers. The largest long-run welfare gains go to high skill worker in the public sector with over 3 percent of consumption. All welfare losses are relatively small, short lived and already dissipated well before generation 0, the generation born when the reforms occur.

We illustrate the welfare effects in the transitions when public investments adjust in figure 5. The pattern of the welfare effects for the spending-base austerity measure is slightly different from that for a tax-based austerity measure. As seen in panel 1 of figure 5, the aggregate welfare effect of the spending-based austerity measure is relatively smaller in the early transitional periods before becoming bigger after 3 transitional periods. The smaller short-run welfare gains are mainly driven by bigger efficiency losses resulting from cutting the investment in infrastructure in short run. However, the long-run aggregate welfare gains for this spending-based reform are relative larger, compared to the tax-based reform. The underlying reason is that the efficiency gain is relatively bigger when more public funds can be released to increase the public investment in infrastructure in the medium and long run. Notably, the middle-age generations suffer most while the newly born and future generations are winners, as seen in the second and third panels of figure 5. The immediate decreases in output in the first two transitional periods force the middle-age generations who are at the height of their earnings potential do pay most the cost of the fiscal consolidation. Welfare losses are observed among the current poor. Welfare gains among the future poor are much larger than the losses that the current poor sustain. Welfare gains of future high skill workers are largest. This is true in the private sector and in the public sector.

Thus, the welfare effects vary significantly across generations. The current old and middle age generations suffer most from the fiscal austerity measures and experience welfare losses while current young workers and future generations born along the transition are beneficiaries. In addition, we find that the spending-based austerity reform is dominated by the tax-based reform in terms of income and welfare in the short run, but becomes dominant in the long run.

Alternative austerity measures to reduce public debt. We next consider alternative fiscal policies to pay for the debt reduction. Specifically, we study a mix of the spending-based and tax-based reforms in which the government cuts either the size of the public sector workforce N_G by 15 percent, public sector wages w_G by 15 percent, or the replacement rate (measured by parameter Ψ_G) of public sector pensions by 15 percent. In all three cases, the government also adjusts either the income tax rate of the three highest income groups (τ_I) or public investments (ΔK_G) in order to balance the government budget constraint. The steady state implications of these reforms are illustrated in table 8 and confirm the previous results. A sizeable reduction in the debt-to-GDP ratio generates large welfare gains. The best policy in terms of steady state consumption is to cut public sector employment and to adjust public infrastructure investment. This policy reform raises steady state consumption by over 5 percent. For that particular policy change the welfare results from table 6 are confirmed again as welfare gains are obtained for all groups. The remaining public sector workers reap larger benefits than workers in the private sector and the welfare gains to richer workers exceed the gains to poorer workers. High income public sector workers can reap benefits of over 5 percent of consumption.

Considering the distributional consequences of cutting public sector employment and raising infrastructure investment, it is again the most preferred policy with groups obtaining welfare gains. Interestingly, the largest welfare gains from this experiment accrue to the high income public sector workers with gains of over 5.2 percent of consumption. Not surprisingly, public sector workers take large welfare losses if public sector wages are cut, regardless of whether the income tax or whether infrastructure investment adjusts. These welfare losses amount to up to 10 percent of consumption.

5 Sensitivity analysis

We next provide sensitivity analysis for a selection of critical parameters for which empirical estimates either do not exist or vary greatly. For the benchmark case we calibrate these parameters from within the model until we match important data moments from Greece. In this section we vary some of these parameters to test the robustness of our results. More specifically, we run the model with alternative values for the (inverse of the) intertemporal elasticity of substitution parameter σ , the infrastructure productivity parameter η , and the capital share parameter α_2 . Whenever we change one of these parameters we also need to adjust other parameters to keep the model output aligned with data moments from Greece. Whenever we increase the intertemporal elasticity parameter σ we need to decrease the time preference parameter β because we otherwise do not match the capital output ratio anymore.

Similarly, if we increase parameter η , too much of the public good G is produced so that we have to lower the total factor productivity in the public goods production sector A_G in order to match the size of this sector to data. Finally, if we increase the capital share parameter α_2 in the final goods production function, we need to lower the capital depreciation rates δ_K and δ_G because capital imports would otherwise drop to unrealistic levels.¹⁰

The results of the sensitivity analysis are summarized in tables 9 and 10. Our results are fairly robust to the suggested changes above when the government simply adjusts a tax or government spending in reaction to the premium shock and in reaction to debt reductions (see table 9). If in addition the government also cuts either public sector employment, public sector wages, or public sector pensions the robustness of our results is also fairly strong, that is, qualitatively identical with small quantitative deviations from our benchmark experiments (compare table 10).

6 Conclusion

We construct a dynamic general equilibrium, overlapping generations economy model to study the macroeconomic and welfare effects of fiscal austerity measures that can be used to reduce the debt-to-GDP ratio. Our model incorporates intra-cohort heterogeneity and a productive government sector as well as key government investment and entitlement programs. We calibrate our model to data from Greece and conduct a quantitative analysis of various fiscal austerity measures.

We first demonstrate that a small open economy with a large debt-to-GDP ratio is exposed severely to external shocks from international capital markets. Considering a small increase in the interest rate due to a risk premium shock we find large output contractions and negative welfare effects. Next, we consider a wide range of tax-based and spending-based austerity measures to reduce the long run debt-to-GDP ratio. We find that these reforms result in a trade off between efficiency losses in the short run and efficiency gains in the long run. That is, there are sharp contractions in aggregate output and consumption in the early stages of the reform. Most notably, the welfare effects vary significantly across generations and types. The current old and middle age generations experience welfare losses while current young workers and future generations born along the transition are beneficiaries. The high skill agents suffer less or gain more from the reforms. Interestingly, we find that the spending-based austerity reform is dominated by the tax-based reform in terms of income and welfare in the short run, but becomes dominant in the long run. A mixed reform that combines tax-based and spending-based measures results in the largest welfare effects.

Our model can be extended to analyze a number of fiscal policy issues. Inclusion of popu-

¹⁰ Note: In a general equilibrium model a change in one parameter does affect all model generated data moments to some extent. So whenever we recalibrate the model in the sensitivity analysis we choose parameters that "most directly" affect the data moment we target. If, for instance, we change parameter value $\sigma = 2.5$ to $\sigma = 3.0$ in the sensitivity analysis, the capital output ratio rises to unrealistic levels. We therefore search for a lower time preference parameter β until the model matches the capital output ratio again. A similar argument can be made for the pairs (η, A_G) and $(\alpha_2, \delta_K = \delta_G)$.

lation ageing into the model could allow us to analyze fundamental factors driving a country's fiscal limit i.e. the dynamic links between ageing, pay-as-you-go social benefits and fiscal sustainability. Including a voting mechanism could be used to study the implementability of fiscal austerity measures. Random disturbances like technology shocks or policy shocks are important to understand fiscal behavior. Accounting for such exogenous economic disturbances would allow us to study the possibility of government default as well as the full spectrum of welfare effects due to the reduction of risk. We leave these issues for future research.

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7 Appendix A

7.1 Progressive income tax

We follow the approach in Ventura (1999) to model the progressive income tax system in Greece. We let \bar{y}_k and τ_k^I denote income tax thresholds and tax rates, respectively. In our benchmark calibration, we use marginal tax rates and income tax thresholds from 2009.¹¹ We condense the tax function to four tax brackets with marginal tax rates as follows:

$$\tau^I = \begin{cases} 0\% & \text{if } 0 < y_{j,t} \leq \bar{y}_1 = \text{€}12,000, \\ 27\% & \text{if } \bar{y}_1 < y_{j,t} \leq \bar{y}_2 = \text{€}30,000, \\ 37\% & \text{if } \bar{y}_2 < y_{j,t} \leq \bar{y}_3 = \text{€}75,000, \\ 40\% & \text{if } y_{j,t} > \bar{y}_3. \end{cases}$$

The progressive income tax can therefore be compactly written as

$$T(y_{j,t}) = T_k + \tau_k^I(y_{j,t} - \bar{y}_k), \quad y_{j,t} \in [\bar{y}_k, \bar{y}_{k+1}],$$

where the parameters of this tax function are the marginal tax rates, τ_k^I , the tax payment thresholds, T_k , and the tax bracket income thresholds, \bar{y}_k . It is assumed that $\tau_1 = 0$, $T_1 = 0$ and $T_k = T_{k-1} + \tau_k^I(\bar{y}_k - \bar{y}_{k-1})$.

7.2 Computation of the steady state and transition

We solve the model numerically using an algorithm similar to Auerbach and Kotlikoff (1987). This algorithm solves non-linear equations using an iterative technique commonly referred to as the Gauss-Seidl method. The algorithm starts with a guess of various endogenous variables and treats them as exogenous. Then, after solving all individual household maximization problems and imposing the budget constraints and market clearing conditions, the algorithm solves for a new set of endogenous variables. If the new set of endogenous variables equals the original guesses, a solution to the system has been found and the algorithm stops. Otherwise, we take linear combinations of the guessed variables and the new solutions for the variables and start all over. Once the algorithm converges to a steady state, we compare the model's outcome to moments in the data. We use a similar algorithm to solve for transitions between two steady states that result from changes in policy variables. We check for uniqueness of equilibrium by trying various starting points for the algorithm. Notice that our solution algorithm is locally stable. We do not have any mathematical proof of global convergence. To our knowledge, there is no formal proof of uniqueness available for this type of Auerbach-Kotlikoff models (see Kotlikoff, Smetters and Walliser (2001)).

8 Appendix B: Tables and Figures

¹¹ http://www.taxexperts.eu/en/GUIDE/TaxExperts_Guide

Parameters	Model:	Observation/Source:
Preferences		
Discount factor	$\beta = 1.032$	To match $\frac{K}{Y}$ and R
Inverse of inter-temp. elast. of subst.	$\sigma = 2.5$	To match $\frac{K}{Y}$ and R
Weight on consumption	$\gamma = 0.34$	To match average hours worked.
Private Production:		
TFP	$A_P = 1$	Normalization
Productivity of public good G	$\alpha_1 = 0.09$	
Capital productivity	$\alpha_2 = 0.35$	
Human capital productivity	$\alpha_3 = 0.65$	
Capital depreciation	$\delta = 10\%$	
Long run growth rate	$g = 1.0\%$	Akram et al. (2011, p. 312)
Public Production:		
TFP for public good production	$A_G = 4.25$	To match public sector size
	$\eta = 0.42$	Sensitivity analysis
Productive civil servants	$\omega_h = 35\%$	Sensitivity analysis
Public capital depreciation	$\delta_G = 10\%$	To match public sector size
Human Capital:		
Efficiency profile	$e_j(\theta)$	To match size of
population growth rate	$n = 0.2\%$	public good sector and hours worked UN Data Country Profile

Table 1: Model Parameters

Policy parameters	Model:	Observation/Source:
Labor Allocation:		
Fraction of gov't employees	$N^G = 20\%$	18% in OECD (2011b, p. 12) and 24% OECD (2011a, p. 8)
Private sector employees	$N^P = 80\%$	OECD (2011, p. 8)
Retirement age	60	62.4 for men and 60.9 for women OECD (2011, p. 9)
Proportion working age	67%	BOG (2005)
Expenditures:		
Public wages markup	$\xi^W = 20\%$	to match public sector wage bill
Replacement rates (generosity of pensions)	$\Psi_P = 50\%$ $\Psi_G = 87\%$	OECD (2011) or to match pension sizes
Investment in public good (in % of priv. sector output)	$\Delta_{K_G} = 5\%$	2% of GDP in capital expenditure, Koutsogeorgopoupou and Turner (2007) to match G/Y of 40%
Residual gov't consumption (in % of priv. sector output)	$\Delta_{C_G} = 0.01\%$	Residual (thrown into ocean), to match income tax revenue
Taxes:		
marg. income tax rates for four income groups	$\tau_I = [0, 0.27, 0.37, 0.4]$	http://www.taxexperts.eu/
income tax polynomial:	$\beta_0 = 0.24$ $\beta_1 = -0.005$ $\beta_2 = 3.0E - 5$	
Consumption tax rate	$\tau_C = 18.9\%$	21% but collection is low (about 50%) share in tax rev. of VAT: 6-7% of GDP OECD (2011,p. 13)
Tax on bequests	$\tau_{Beq} = 15\%$	To match tax revenue of income tax
Social security tax-private	$\tau_{SS}^P = 12\%$	To match pension deficit 3 – 4% of GDP
Social security tax-public	$\tau_{SS}^G = 15\%$	To match pension deficit 1 – 1.5% of GDP

Table 2: Policy Parameters

Moments I	Model:	Data:	Observation/Source:
Capital output ratio: $\frac{K}{Y}$	1.56	1.54	IMF (2006, p. 31)
Annual interest rate: r	4.0	4.5%	OECD (2011b, p. 5)
debt-to-GDP ratio:	105%	105%	Eurostat (2009)
Public sector share of GDP: $\frac{G}{Y}$	40.1%	40%	Based on Economy_of_Greece
Hours worked/week:	37.6	38.64	42 hours according to OECD StatExtracts
Hours worked/week, private:	38.7	38.64	
Hours worked/week, public:	37.6	28.98	75% of average work hours, OECD (2011b, p. 12)
CA deficit in % of GDP	-14%	10 – 14.4%	CA balance in % of GDP Akram et al. (2011, p. 309) and Ministry of Finance (2011, p. 15)

Table 3: Macroeconomic Aggregates: Model Outcomes vs. Greek Data

Moments II	Model:	Data:	Observation/Source:
Tax Revenues: (all in % of GDP)			
Total tax revenue	36.6%	32 – 34.2%	OECD 2011, p. 13 and Akram et al. (2011, p. 308)
Income tax revenue	13.4%	7%	OECD 2011, p. 13
Consumption tax revenue	12.9%	7%	OECD 2011, p. 13
Soc.Sec.Rev.:private sector	7.8%		To match pension deficit
Soc.Sec.Rev.:public sector	1.8%		To match pension deficit
Bequest tax revenue	0.7%	1%	Property tax, OECD 2011, p. 13
Expenditures: (all in % of GDP)			
Wage bill public sector	7.5%	11.5%	Koutsogeorgopoulou and Turner (2007, p 8) 33% of total wage bill in OECD (2011, p. 8)
Wage bill private sector	65.0%	20%	33% of total wage bill, OECD (2011, p. 8)
Private pensions	10.4%	8.5%	residual from below
Public pension	3.4%	2.5 – 5%	Hellenic Country Fiche (2011, p. 19)
All pension payments	13.9%	11.5 – 13.9%	OECD 2011, p. 9 and Hellenic Country Fiche (2011, p. 19)
Debt-to-GDP	105%	105%	http://stats.oecd.org
Pension Deficit: (all in % of GDP)			
Pension deficit	–4.2%	–4 to –5% of GDP	O'Donnel and Tinios (2003) and Greek Finance Ministry (2012)
Pension deficit priv. sector	–2.64%	–3 to –4% of GDP	own calculations
Pension deficit pub. sector	–1.6%	–1 to –1.5% of GDP	own calculations

Table 4: Fiscal Activities: Model vs. Greek Data

	[1] τ_I	[2] τ_C	[3] Δ_{K_G}
Output Y	98.31	98.39	98.59
Capital K	109.98	109.40	109.96
Capital in final K_P	96.72	96.81	97.01
Human capital private H_P	99.25	99.33	99.34
Human capital public H_G	98.96	99.08	99.08
Public good G	99.40	99.46	100.88
Consumption C	99.56	100.11	99.89
Current account: CA	-76.95	-78.04	-77.68
Interest rate r	103.78	103.78	103.78
Risk premium	121.97	121.97	121.97
Wages w	99.05	99.06	99.25
Income tax τ_I	100.37	100.00	100.00
Consumption tax τ_C	100.00	97.19	100.00
Infrastruc. Inv. Δ_{K_G}	100.00	100.00	104.89
Debt to GDP ratio in %	105.00	105.00	105.00
Total govt spending	98.78	98.86	99.34
Bonds	98.31	98.39	98.59
Govt consumption C_G	100.00	100.00	100.00
Govt investment I_{K_G}	100.00	100.00	103.42
Pub. sec. wages	98.02	98.14	98.34
Pensions	98.26	98.35	98.53
Tax revenue	100.05	99.14	100.21
Bequest tax rev.	104.87	104.41	104.90
Cons tax rev.	99.56	97.28	99.89
Soc. sec. tax rev.	98.25	98.35	98.54
Income tax rev.	101.55	101.20	101.45
TaxableInc: all	99.71	99.76	99.98
TaxableInc: labor	98.12	98.22	98.42
TaxableInc: pension	98.30	98.39	98.58
TaxableInc: asset	109.74	109.44	109.86
Welfare measures			
Aggregate Comp.Cons. in % of GDP	0.22	-0.09	0.05
Aggregate-Private in % of GDP	0.16	-0.09	0.02
Aggregate-Public in % of GDP	0.06	-0.00	0.03
Private-Low income: Avge.% Δ in C	-0.07	-0.48	-0.28
Private-High income: Avge.% Δ in C	0.47	0.00	0.21
Public-Low income: Avge.% Δ in C	0.14	-0.28	-0.07
Public-High income: Avge.% Δ in C	0.81	0.27	0.51

Table 5: A Risk-Premium Shock and the Long Run Aggregate and Welfare Effects. Greece now reports its true debt level so that the risk premium increases. Note that the government does not adjust the debt level yet and lets either taxes or public spending adjust to clear the government budget constraint in reaction to the higher risk premium that it now faces. τ_I is labor tax, τ_C is consumption tax, and Δ_{K_G} is public investment. The benchmark steady state is normalized to 100, all results are in relation to this steady state. Welfare results are reported as compensating consumption units as fraction of pre-reform steady state GDP. In the last four rows we report compensating consumption units as percentage of pre-reform steady state consumption per household type. Negative numbers represent welfare gains.

	[1] N_G, τ_I	[2] N_G, Δ_{K_G}	[3] w_G, τ_I	[4] w_G, Δ_{K_G}	[5] Ψ_G, τ_I	[6] Ψ_G, Δ_{K_G}
Output Y	99.17	101.36	98.00	99.61	97.98	98.87
Capital K	109.54	109.52	112.15	112.06	114.27	114.21
Capital in final K_P	97.58	99.73	96.42	98.01	96.40	97.28
Human capital private H_P	101.27	102.11	98.66	99.22	98.92	99.20
Human capital public H_G	85.90	86.59	102.42	102.95	98.94	99.30
Public good G	91.56	100.99	101.39	109.57	99.38	103.98
Consumption C	98.17	100.66	97.82	99.64	98.99	100.00
Current account: CA	-79.74	-85.12	-72.95	-77.06	-69.74	-72.03
Interest rate r	103.78	103.78	103.78	103.78	103.78	103.78
Risk premium	121.97	121.97	121.97	121.97	121.97	121.97
Wages w	97.93	99.27	99.32	100.39	99.05	99.67
Income tax τ_I	103.28	100.00	102.31	100.00	101.17	100.00
Consumption tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
Infrastruc. Inv. Δ_{K_G}	100.00	123.21	100.00	119.89	100.00	112.06
Debt to GDP ratio in %	105.00	105.00	105.00	105.00	105.00	105.00
Total govt spending	95.59	99.64	95.46	98.55	97.69	99.45
Bonds	99.17	101.36	98.00	99.61	97.98	98.87
Govt consumption C_G	100.00	100.00	100.00	100.00	100.00	100.00
Govt investment I_{K_G}	100.00	124.88	100.00	119.42	100.00	110.79
Pub. sec. wages	84.12	85.95	86.46	87.85	97.99	98.97
Pensions	95.53	97.58	95.20	96.72	94.40	95.25
Tax revenue	98.52	99.51	98.09	98.86	100.00	100.47
Bequest tax rev.	105.90	106.22	106.86	107.09	107.96	108.06
Cons tax rev.	98.17	100.66	97.82	99.64	98.99	100.00
Soc. sec. tax rev.	96.32	98.44	95.81	97.38	97.98	98.89
Income tax rev.	100.03	98.84	99.52	98.75	101.98	101.67
TaxableInc: all	98.06	100.11	96.09	97.59	99.04	99.89
TaxableInc: labor	96.76	98.99	94.14	95.77	97.79	98.73
TaxableInc: pension	93.55	95.58	93.50	95.00	92.55	93.39
TaxableInc: asset	109.39	110.47	109.22	109.97	111.92	112.32
Welfare measures						
Agg. Comp.Cons. % of GDP	0.84	-0.38	1.44	0.53	0.59	0.07
Agg.-Private % of GDP	0.75	-0.24	0.24	-0.53	0.20	-0.22
Agg.-Public % of GDP	0.08	-0.14	1.20	1.06	0.38	0.30
Priv.-Low inc.: Avge.% Δ in C	0.84	-0.69	-0.11	-1.28	-0.11	-0.76
Priv.-High inc.: Avge.% Δ in C	1.67	-0.30	0.73	-0.78	0.60	-0.22
Pub.-Low inc.: Avge.% Δ in C	1.05	-0.45	10.57	9.37	1.43	0.79
Pub.-High inc.: Avge.% Δ in C	0.34	-1.75	11.03	9.39	5.19	4.26

Table 6: A Risk-Premium Shock and the Long Run Aggregate and Welfare Effects. Greece now reports its true debt level so that the risk premium increases. Note that the government does not adjust the debt level yet and lets a mix of taxes and public spending adjust to clear the government budget constraint in reaction to the higher risk premium that it now faces: [1] (N_G, τ_I) , is public sector size lowered by 85 percent with labor taxes adjustin; [2] (N_G, Δ_{K_G}) , is public sectorsize lowered by 15 percent and infrastructure investments adjusting; [3] (w_G, τ_I) , is public sector wages lowered by 15 and income taxes adjusting; [4] (w_G, τ_I) , is public sector wages lowered by 15 percent and infrastructure investments adjusting; [5] (Ψ_G, τ_I) are public pension payments lowered by 15 percent and income tax adjusting; and [6] (Ψ_G, Δ_{K_G}) are public pension payments lowered by 15 percent and infrastructure investments adjusting. The benchmark steady state is normalized to 100, all results are in relation to this steady state. Welfare results are reported as compensating consumption units as fraction of pre-reform steady state GDP. In the last four rows we report compensating consumption units as percentage of pre-reform steady state consumption per household type. Negative numbers represent welfare gains.

	[1] τ_I	[2] τ_C	[3] Δ_{K_G}
Output Y	103.67	104.34	105.34
Capital K	109.07	105.74	106.72
Capital in final K_P	108.40	109.10	110.15
Human capital private H_P	100.95	101.71	101.72
Human capital public H_G	103.18	101.80	101.80
Public good G	101.83	101.04	108.27
Consumption C	102.56	103.97	103.94
Current account: CA	-107.40	-114.11	-115.26
Interest rate r	89.78	89.78	89.78
Risk premium	40.16	40.16	40.16
Wages w	102.69	102.58	103.57
Income tax τ_I	102.81	100.00	100.00
Consumption tax τ_C	100.00	93.84	100.00
Infrastruc. Inv. Δ_{K_G}	100.00	100.00	111.91
Debt to GDP ratio in %	85.02	85.02	85.02
Total govt spending	93.96	93.91	96.29
Bonds	83.94	84.48	85.30
Govt consumption C_G	100.00	100.00	100.00
Govt investment I_{K_G}	100.00	100.00	117.89
Pub. sec. wages	105.95	104.43	105.43
Pensions	104.24	104.34	105.36
Tax revenue	101.84	99.32	102.18
Bequest tax rev.	95.31	93.66	94.55
Cons tax rev.	102.56	97.59	103.94
Soc. sec. tax rev.	104.10	104.35	105.36
Income tax rev.	99.88	97.67	98.61
TaxableInc: all	96.30	97.20	98.14
TaxableInc: labor	98.89	100.68	101.65
TaxableInc: pension	95.80	93.34	94.25
TaxableInc: asset	82.56	81.68	82.45
Welfare measures			
Aggregate Comp.Cons. in % of GDP	-0.82	-1.63	-1.61
Aggregate-Private in % of GDP	-0.59	-1.34	-1.32
Aggregate-Public in % of GDP	-0.23	-0.29	-0.29
Private-Low income: Avge.% Δ in C	-0.81	-1.79	-1.76
Private-High income: Avge.% Δ in C	-1.14	-2.56	-2.54
Public-Low income: Avge.% Δ in C	-1.45	-1.60	-1.57
Public-High income: Avge.% Δ in C	-2.29	-3.11	-3.08

Table 7: A Risk-Premium Shock, Debt Reduction and the Long Run Aggregate and Welfare Effects. Greece now reports its true debt level so that the risk premium increases. Note that the government does now reduce the debt level to 85 percent of GDP and lets either taxes or public spending adjust to clear the government budget constraint in reaction to the higher risk premium that it now faces. τ_I is income tax, τ_C is consumption tax, and Δ_{K_G} is public investment. The benchmark steady state is normalized to 100, all results are in relation to this steady state. Welfare results are reported as compensating consumption units as fraction of pre-reform steady state GDP. In the last four rows we report compensating consumption units as percentage of pre-reform steady state consumption per household type. Negative numbers represent welfare gains.

	[1] N_G, τ_I	[2] N_G, Δ_{K_G}	[3] w_G, τ_I	[4] w_G, Δ_{K_G}	[5] Ψ_G, τ_I	[6] Ψ_G, Δ_{K_G}
Output Y	104.32	108.44	103.11	106.49	103.24	105.66
Capital K	110.29	108.33	111.39	109.14	113.08	111.70
Capital in final K_P	109.08	113.40	107.82	111.35	107.95	110.49
Human capital private H_P	102.87	104.65	100.27	101.60	100.61	101.57
Human capital public H_G	88.21	89.63	105.06	106.27	102.24	103.33
Public good G	92.98	108.77	102.90	118.08	101.29	111.84
Consumption C	100.73	105.10	100.17	103.70	101.58	104.21
Current account: CA	-107.28	-120.95	-102.49	-114.65	-100.29	-108.67
Interest rate r	89.78	89.78	89.78	89.78	89.78	89.78
Risk premium	40.16	40.16	40.16	40.16	40.16	40.16
Wages w	101.41	103.63	102.84	104.82	102.61	104.03
Income tax τ_I	106.31	100.00	104.99	100.00	103.65	100.00
Consumption tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
Infrastruc. Inv. Δ_{K_G}	100.00	131.03	100.00	128.25	100.00	118.07
Debt to GDP ratio in %	85.02	85.02	85.02	85.02	85.02	85.02
Total govt spending	89.87	96.69	89.86	95.63	92.52	96.66
Bonds	84.47	87.81	83.49	86.23	83.59	85.56
Govt consumption C_G	100.00	100.00	100.00	100.00	100.00	100.00
Govt investment I_{K_G}	100.00	142.09	100.00	136.58	100.00	124.75
Pub. sec. wages	89.45	92.88	91.83	94.68	104.92	107.50
Pensions	100.72	104.61	100.39	103.58	99.81	102.14
Tax revenue	99.87	101.63	99.48	100.92	101.62	102.70
Bequest tax rev.	96.96	96.80	97.37	96.82	98.44	98.16
Cons tax rev.	100.73	105.10	100.17	103.70	101.58	104.21
Soc. sec. tax rev.	101.50	105.49	100.97	104.25	103.55	106.01
Income tax rev.	98.03	95.81	97.86	96.11	100.44	99.14
TaxableInc: all	94.13	97.72	92.74	95.03	96.36	98.53
TaxableInc: labor	96.94	101.09	95.57	98.16	99.67	102.21
TaxableInc: pension	89.75	93.32	87.31	90.16	89.23	91.38
TaxableInc: asset	82.79	83.25	82.22	82.33	84.75	84.94
Welfare measures						
Agg. Comp.Cons. in % of GDP	0.03	-2.15	0.64	-1.15	-0.30	-1.62
Agg.-Priv. % of GDP	0.17	-1.62	-0.42	-1.95	-0.51	-1.61
Agg.-Pub. % of GDP	-0.14	-0.53	1.06	0.80	0.21	-0.02
Priv.-Low inc.: Avge.% Δ in C	0.27	-2.21	-0.75	-2.79	-0.79	-2.27
Priv.-High inc.: Avge.% Δ in C	0.32	-3.07	-0.75	-3.58	-0.95	-3.00
Pub.-Low inc.: Avge.% Δ in C	-0.54	-2.99	10.35	8.22	1.03	-0.49
Pub.-High inc.: Avge.% Δ in C	-1.73	-5.29	8.78	5.74	2.55	0.24

Table 8: A Risk-Premium Shock, Debt Reduction, and the Long Run Aggregate and Welfare Effects. Greece now reports its true debt level so that the risk premium increases. Note that the government does now reduce the debt level to 85 percent of GDP and let a mix of taxes or public spending adjust to clear the government budget constraint in reaction to the higher risk premium that it now faces: [1] (N_G, τ_I), is public sector size lowered by 85 percent with labor taxes adjusting; [2] (N_G, Δ_{K_G}), is public sector size lowered by 15 percent and infrastructure investments adjusting; [3] (w_G, τ_I), is public sector wages lowered by 15 percent and income taxes adjusting; [4] (w_G, τ_I), is public sector wages lowered by 15 percent and infrastructure investments adjusting; [5] (Ψ_G, τ_I) are public pension payments lowered by 15 percent and income tax adjusting; and [6] (Ψ_G, Δ_{K_G}) are public pension payments lowered by 15 percent and infrastructure investments adjusting. The benchmark steady state is normalized to 100, all results are in relation to this steady state. Welfare results are reported as compensating consumption units as fraction of pre-reform steady state GDP. In the last four rows we report compensating consumption units as percentage of pre-reform steady state consumption per household type. Negative numbers represent welfare gains.

		Debt-to-GDP: 105%			Debt-to-GDP: 85%		
		[1] τ_I	[2] τ_C	[3] Δ_{K_G}	[4] τ_I	[5] τ_C	[6] Δ_{K_G}
Benchmark:	Output Y	98.31	98.39	98.59	103.67	104.34	105.34
$\sigma = 2.50$	Capital K	109.98	109.40	109.96	109.07	105.74	106.72
$\beta = 1.03$	Cap. dom. prod. K_P	96.72	96.81	97.01	108.40	109.10	110.15
$\eta = 0.42$	Consumption C	99.56	100.11	99.89	102.56	103.97	103.94
$A_G = 4.25$	Income tax τ_I	100.37	100.00	100.00	102.81	100.00	100.00
$\alpha_2 = 0.35$	Consumption tax τ_C	100.00	97.19	100.00	100.00	93.84	100.00
$\delta_K = 0.10$	Govt investment I_{K_G}	100.00	100.00	103.42	100.00	100.00	117.89
Sensitivity analysis: σ							
$\sigma = 1.50$ $\beta = 1.01$	Output Y	97.79	98.00	98.44	103.95	104.34	104.09
	Capital K	118.08	117.29	118.26	89.35	89.13	88.81
	Cap. dom. prod. K_P	96.21	96.43	96.86	108.70	109.11	108.84
	Consumption C	99.68	100.76	100.41	101.48	101.62	101.69
	Income tax τ_I	100.79	100.00	100.00	101.18	100.00	100.00
	Consumption tax τ_C	100.00	94.90	100.00	100.00	102.04	100.00
$\sigma = 2.00$ $\beta = 1.02$	Govt investment I_{K_G}	100.00	100.00	107.87	100.00	100.00	95.84
	Output Y	97.97	98.14	98.49	104.42	104.84	104.82
	Capital K	112.21	111.25	112.08	80.14	80.11	80.04
	Cap. dom. prod. K_P	96.39	96.56	96.91	109.18	109.63	109.60
	Consumption C	99.22	100.13	99.80	100.69	101.19	101.23
	Income tax τ_I	100.66	100.00	100.00	101.42	100.00	100.00
$\sigma = 3.00$ $\beta = 1.04$	Consumption tax τ_C	100.00	95.66	100.00	100.00	100.39	100.00
	Govt investment I_{K_G}	100.00	100.00	106.19	100.00	100.00	99.64
	Output Y	98.28	98.36	98.56	103.44	103.98	105.27
	Capital K	108.16	107.49	108.10	105.23	103.05	104.37
	Cap. dom. prod. K_P	96.70	96.78	96.97	108.16	108.72	110.07
	Consumption C	99.27	99.83	99.58	101.61	103.39	103.63
$\eta = 0.35$ $A_G = 4.29$	Income tax τ_I	100.34	100.00	100.00	102.76	100.00	100.00
	Consumption tax τ_C	100.00	97.06	100.00	100.00	91.62	100.00
	Govt investment I_{K_G}	100.00	100.00	103.34	100.00	100.00	118.69
	Output Y	98.30	98.39	98.55	103.70	104.35	105.19
	Capital K	109.99	109.40	109.97	109.07	105.74	106.77
	Cap. dom. prod. K_P	96.72	96.80	96.97	108.43	109.12	109.99
$\eta = 0.50$ $A_G = 4.21$	Consumption C	99.55	100.11	99.85	102.58	103.99	103.80
	Income tax τ_I	100.37	100.00	100.00	102.81	100.00	100.00
	Consumption tax τ_C	100.00	97.19	100.00	100.00	93.83	100.00
	Govt investment I_{K_G}	100.00	100.00	103.35	100.00	100.00	117.82
	Output Y	98.32	98.40	98.64	103.63	104.32	105.51
	Capital K	109.98	109.40	109.95	109.08	105.75	106.67
$\alpha_2 = 0.30$ $\delta_K = 0.07$ $\delta_{K_G} = 0.07$	Cap. dom. prod. K_P	96.74	96.82	97.05	108.36	109.08	110.32
	Consumption C	99.58	100.12	99.93	102.53	103.95	104.09
	Income tax τ_I	100.36	100.00	100.00	102.81	100.00	100.00
	Consumption tax τ_C	100.00	97.19	100.00	100.00	93.83	100.00
	Govt investment I_{K_G}	100.00	100.00	103.39	100.00	100.00	117.86
	Output Y	98.41	98.48	98.65	103.36	103.99	104.40
Sensitivity analysis: α_2							
$\alpha_2 = 0.30$ $\delta_K = 0.07$ $\delta_{K_G} = 0.07$	Capital K	111.45	111.09	111.52	83.84	83.26	83.58
	Cap. dom. prod. K_P	96.57	96.64	96.81	108.88	109.54	109.98
	Consumption C	99.58	100.07	99.86	99.98	101.36	101.32
	Income tax τ_I	100.30	100.00	100.00	102.27	100.00	100.00
	Consumption tax τ_C	100.00	97.32	100.00	100.00	97.03	100.00
	Govt investment I_{K_G}	100.00	100.00	103.12	100.00	100.00	107.63

Table 9: Sensitivity analysis with and without debt reductions and adjustments in taxes or infrastructure investments.

		[1] N_G, τ_I	[2] $N_G, \Delta K_G$	[3] w_G, τ_I	[4] $w_G, \Delta K_G$	[5] Ψ_G, τ_I	[6] $\Psi_G, \Delta K_G$
Benchmark:	Output Y	104.32	108.44	103.11	106.49	103.24	105.66
$\sigma = 2.50$	Capital K	110.29	108.33	111.39	109.14	113.08	111.70
$\beta = 1.03$	Cap. dom. K_P	109.08	113.40	107.82	111.35	107.95	110.49
$\eta = 0.42$	Cons. C	100.73	105.10	100.17	103.70	101.58	104.21
$A_G = 4.25$	Income tax τ_I	106.31	100.00	104.99	100.00	103.65	100.00
$\alpha_2 = 0.35$	Cons. tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
$\delta_K = 0.10$	Govt inv. I_{K_G}	100.00	142.09	100.00	136.58	100.00	124.75
Sensitivity analysis: σ							
$\sigma = 1.50$ $\beta = 1.01$	Output Y	101.63	107.70	103.07	105.69	103.63	104.50
	Capital K	108.47	89.76	92.67	90.31	95.12	94.03
	Cap. dom. K_P	106.27	112.61	107.77	110.52	108.36	109.27
	Cons. C	97.30	102.70	98.88	101.52	101.15	102.10
	Income tax τ_I	116.69	100.00	104.19	100.00	102.10	100.00
	Cons. tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
	Govt inv. I_{K_G}	100.00	131.27	100.00	123.18	100.00	103.01
Benchmark:	Output Y	104.71	108.31	103.49	106.42	104.02	105.36
$\sigma = 2.50$	Capital K	81.68	79.94	80.14	78.22	86.01	84.77
$\beta = 1.03$	Cap. dom. K_P	109.49	113.26	108.21	111.28	108.77	110.17
	Cons. C	98.56	102.05	97.56	100.66	100.23	101.70
	Income tax τ_I	106.49	100.00	104.89	100.00	102.60	100.00
	Cons. tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
	Govt inv. I_{K_G}	100.00	134.26	100.00	126.87	100.00	109.37
$\sigma = 3.00$ $\beta = 1.04$	Output Y	100.31	108.49	102.80	106.27	102.85	105.46
	Capital K	118.21	110.54	108.15	106.19	109.95	109.03
	Cap. dom. K_P	104.89	113.45	107.50	111.12	107.54	110.28
	Cons. C	96.40	105.04	99.21	102.83	100.51	103.37
	Income tax τ_I	118.41	100.00	104.94	100.00	103.82	100.00
	Cons. tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
	Govt inv. I_{K_G}	100.00	145.69	100.00	139.37	100.00	128.01
Sensitivity analysis: η							
$\eta = 0.35$ $A_G = 4.29$	Output Y	104.24	107.96	103.12	106.23	103.26	105.47
	Capital K	110.27	108.47	111.43	109.20	113.08	111.75
	Cap. dom. K_P	109.00	112.88	107.83	111.08	107.97	110.28
	Cons. C	100.68	104.66	100.17	103.46	101.60	104.04
	Income tax τ_I	106.16	100.00	105.13	100.00	103.65	100.00
	Cons. tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
	Govt inv. I_{K_G}	100.00	141.63	100.00	136.37	100.00	124.61
$\eta = 0.50$ $A_G = 4.21$	Output Y	104.46	109.02	103.06	106.80	103.21	105.88
	Capital K	110.25	108.19	111.41	109.09	113.09	111.66
	Cap. dom. K_P	109.23	113.99	107.76	111.67	107.92	110.71
	Cons. C	100.86	105.61	100.13	103.97	101.56	104.41
	Income tax τ_I	106.30	100.00	104.99	100.00	103.65	100.00
	Cons. tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
	Govt inv. I_{K_G}	100.00	142.62	100.00	136.85	100.00	124.77
Sensitivity analysis: α_2							
$\alpha_2 = 0.30$ $\delta_K = 0.07$ $\delta_K = 0.07$	Output Y	103.05	107.83	102.90	105.70	103.04	104.86
	Capital K	105.71	103.36	86.27	85.47	88.43	87.95
	Cap. dom. K_P	108.56	113.59	108.40	111.35	108.54	110.46
	Cons. C	98.49	103.87	98.02	101.30	99.38	101.62
	Income tax τ_I	108.08	100.00	105.11	100.00	103.43	100.00
	Cons. tax τ_C	100.00	100.00	100.00	100.00	100.00	100.00
	Govt inv. I_{K_G}	100.00	149.54	100.00	128.27	100.00	116.86

Table 10: Sensitivity analysis for debt reduction to 85 percent of GDP and various austerity measures.

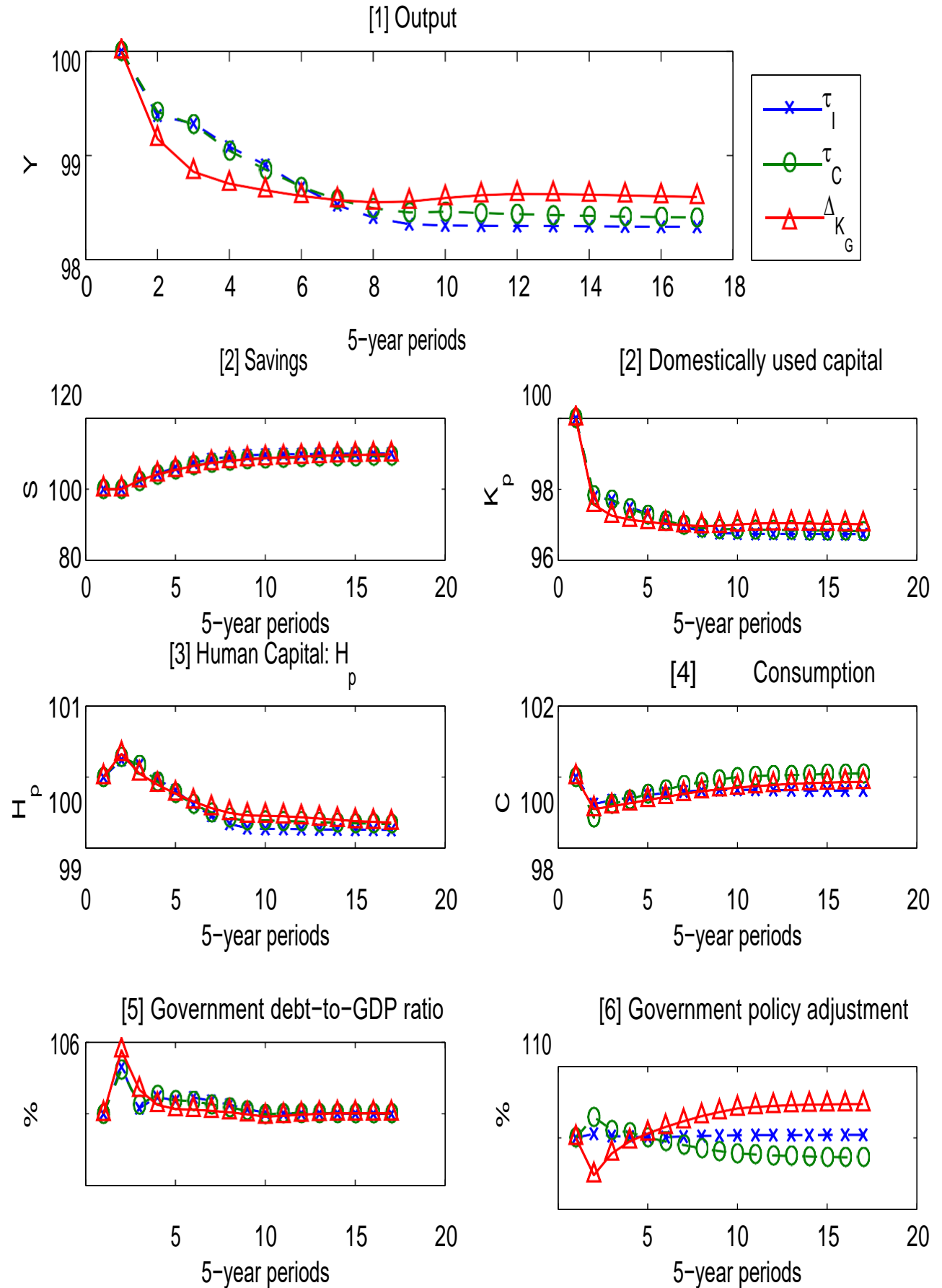


Figure 1: A Risk-Premium Shock and the Transition Dynamics of Key Aggregates. Either

[1] income tax τ_I or [2] consumption tax τ_C or [3] public investment Δ_{K_G} adjusts to accommodate the increase in the risk premium due to truthful reporting of the debt level of 105 percent of GDP.

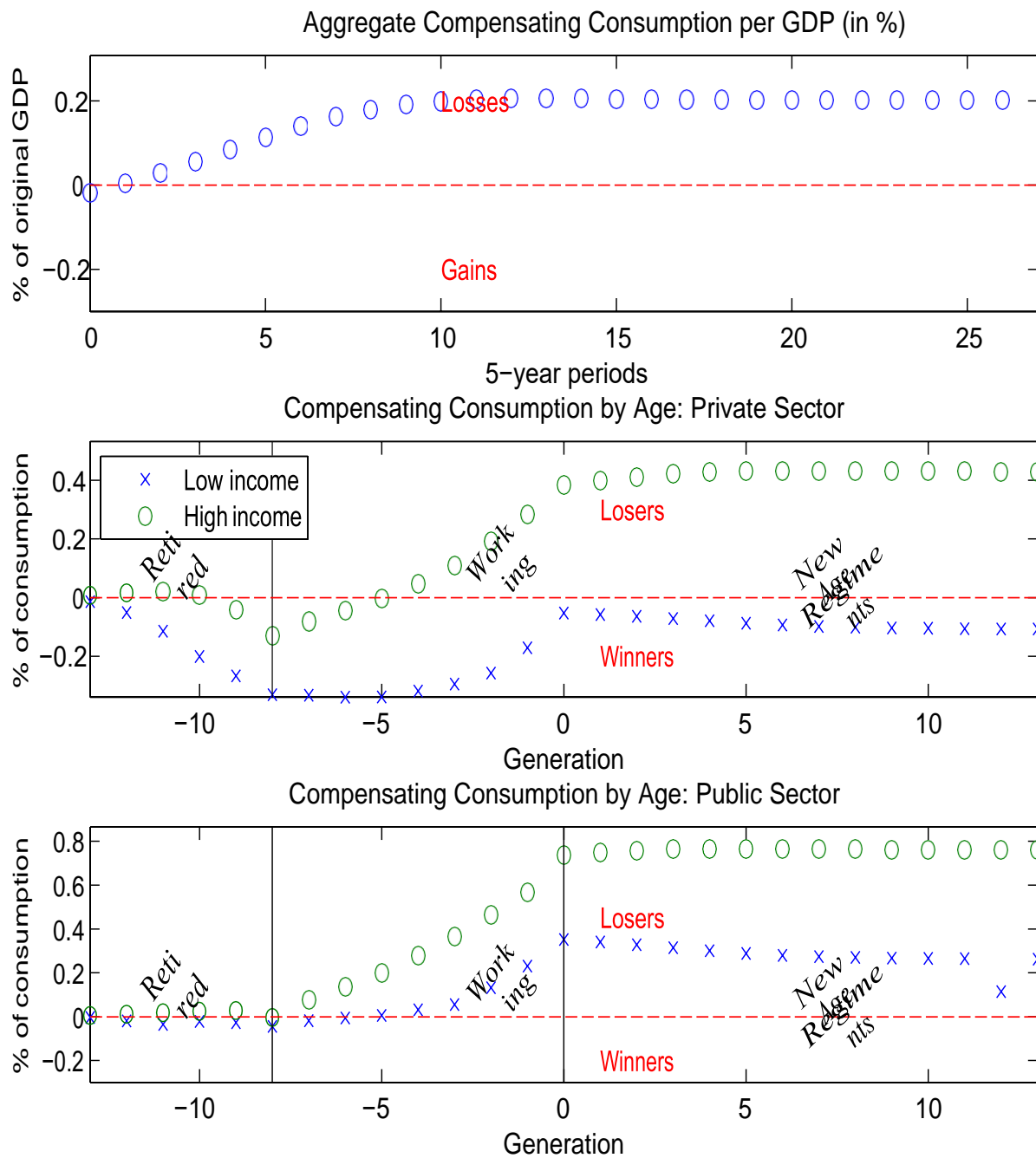


Figure 2: A Risk-Premium Shock and Welfare Dynamics. The income tax adjusts to accommodate the increase in the risk premium due to truthful reporting of the debt level of 105 percent of GDP.

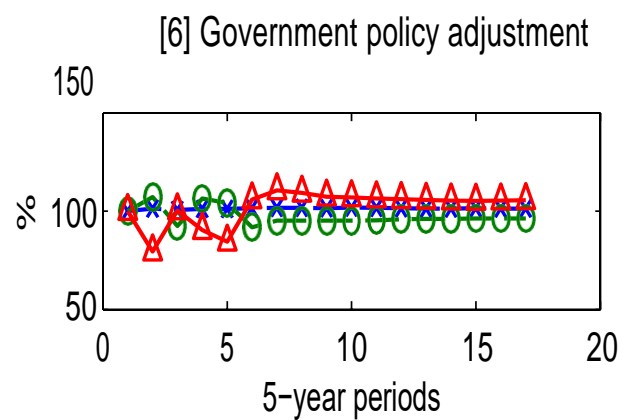
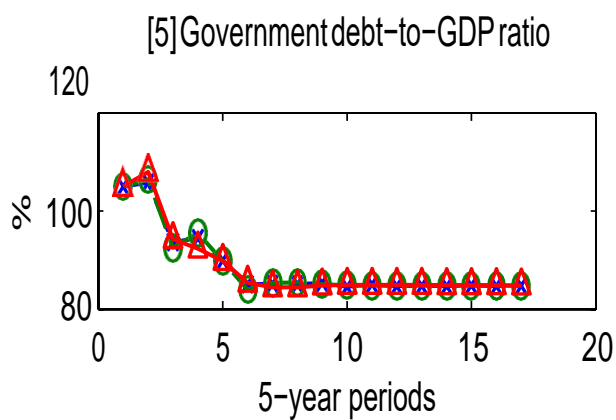
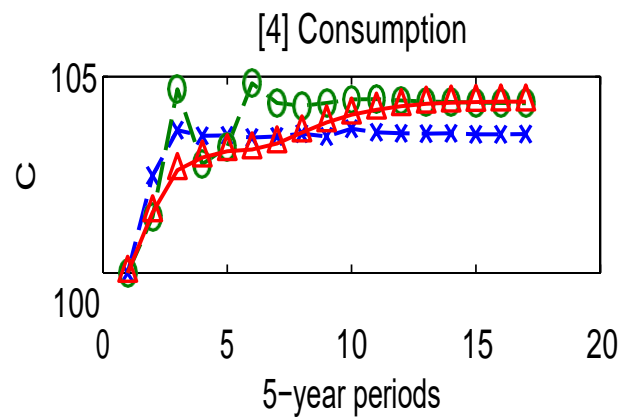
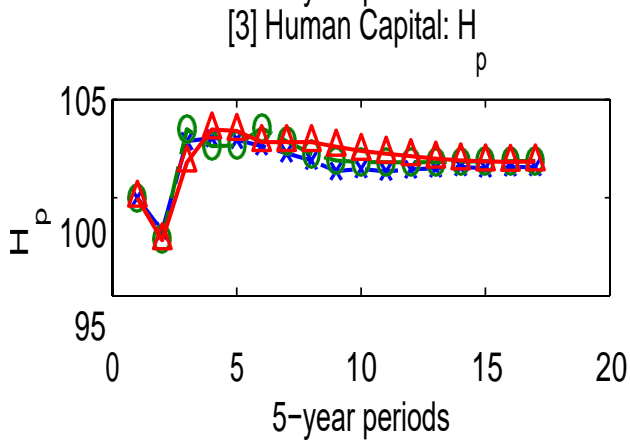
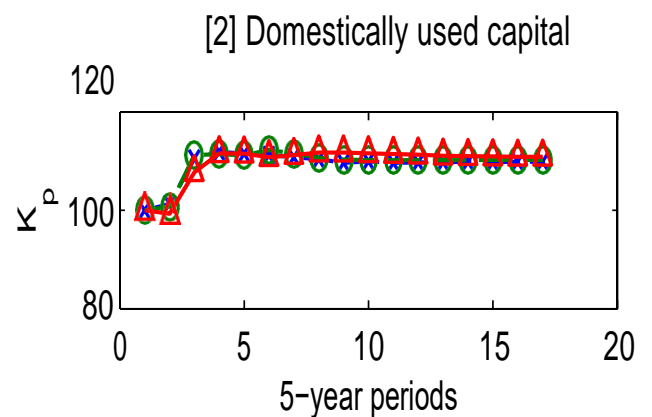
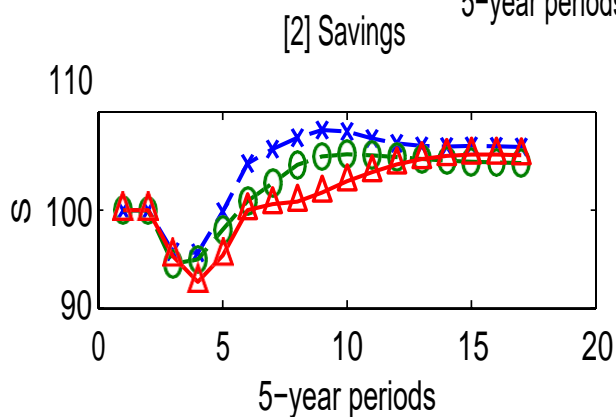
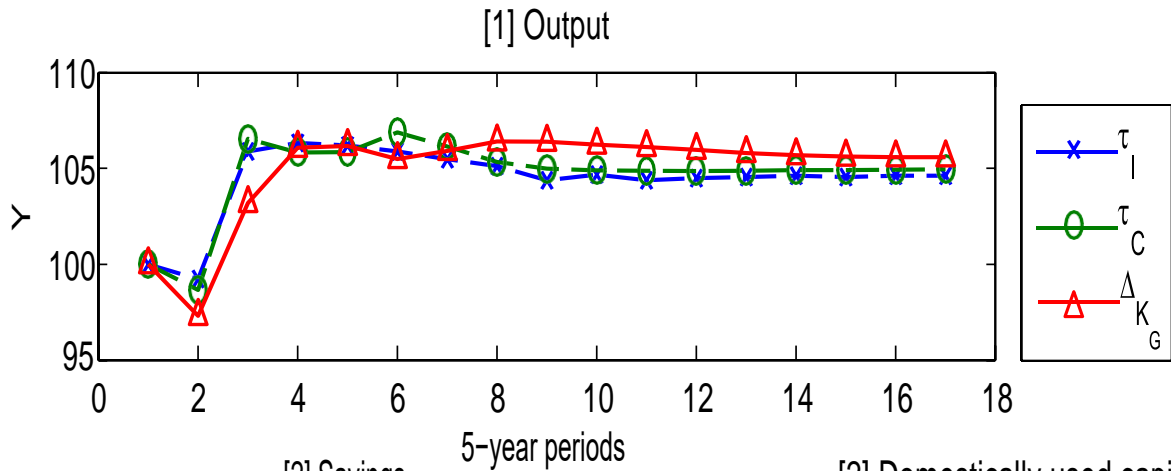


Figure 3: A Risk-Premium Shock, Debt Reduction and the Transition Dynamics of Key Aggregates. Either [1] income tax τ_I or [2] consumption tax τ_C or [3] public investment Δ_{K_G} adjusts to accommodate the reduction of debt to to 85 percent of GDP and the risk premium shock.

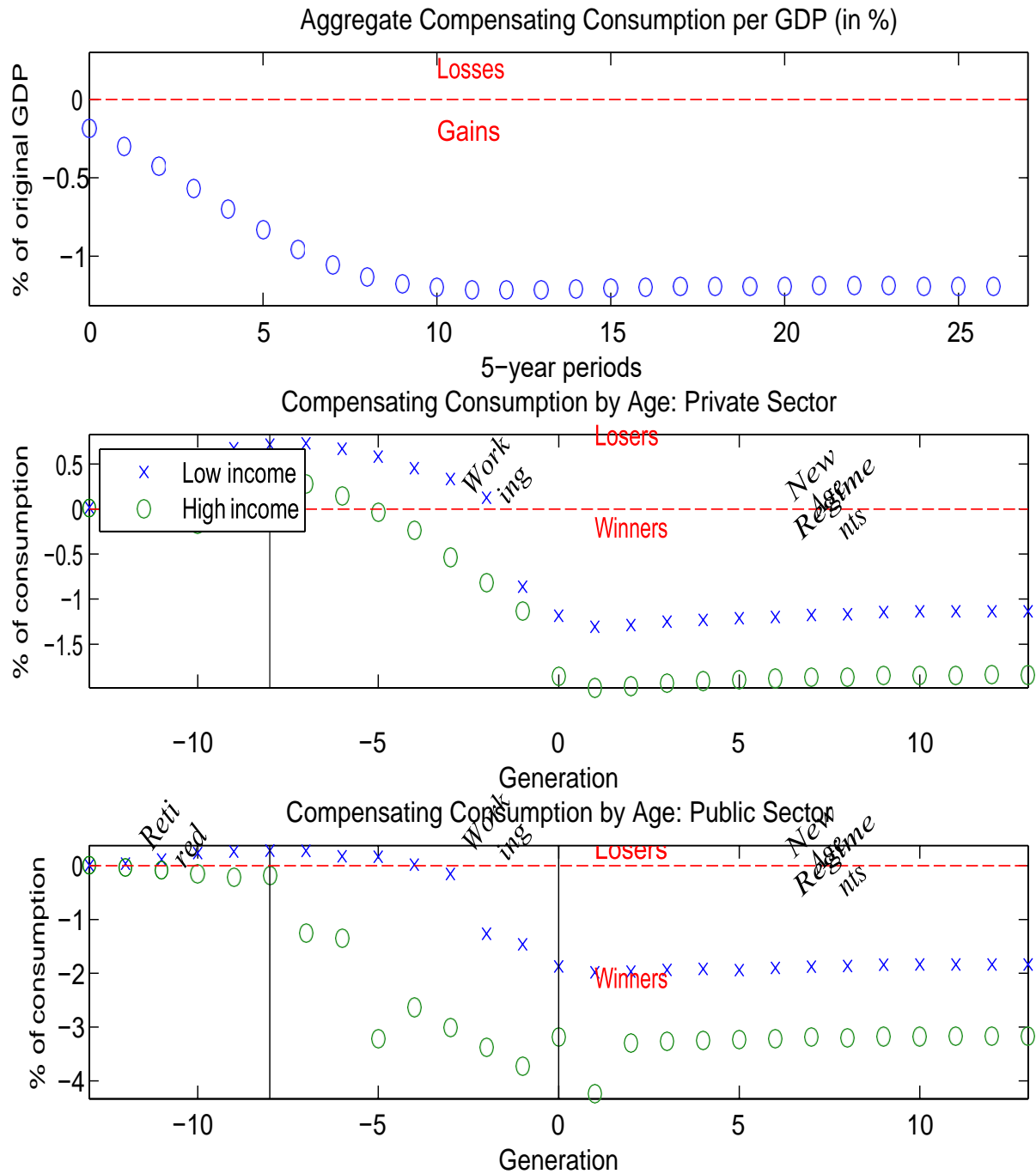


Figure 4: A Risk-Premium Shock, Debt Reduction and Welfare Dynamics. The income tax adjusts to accommodate the decrease of debt to 85 percent of GDP and the risk premium shock.

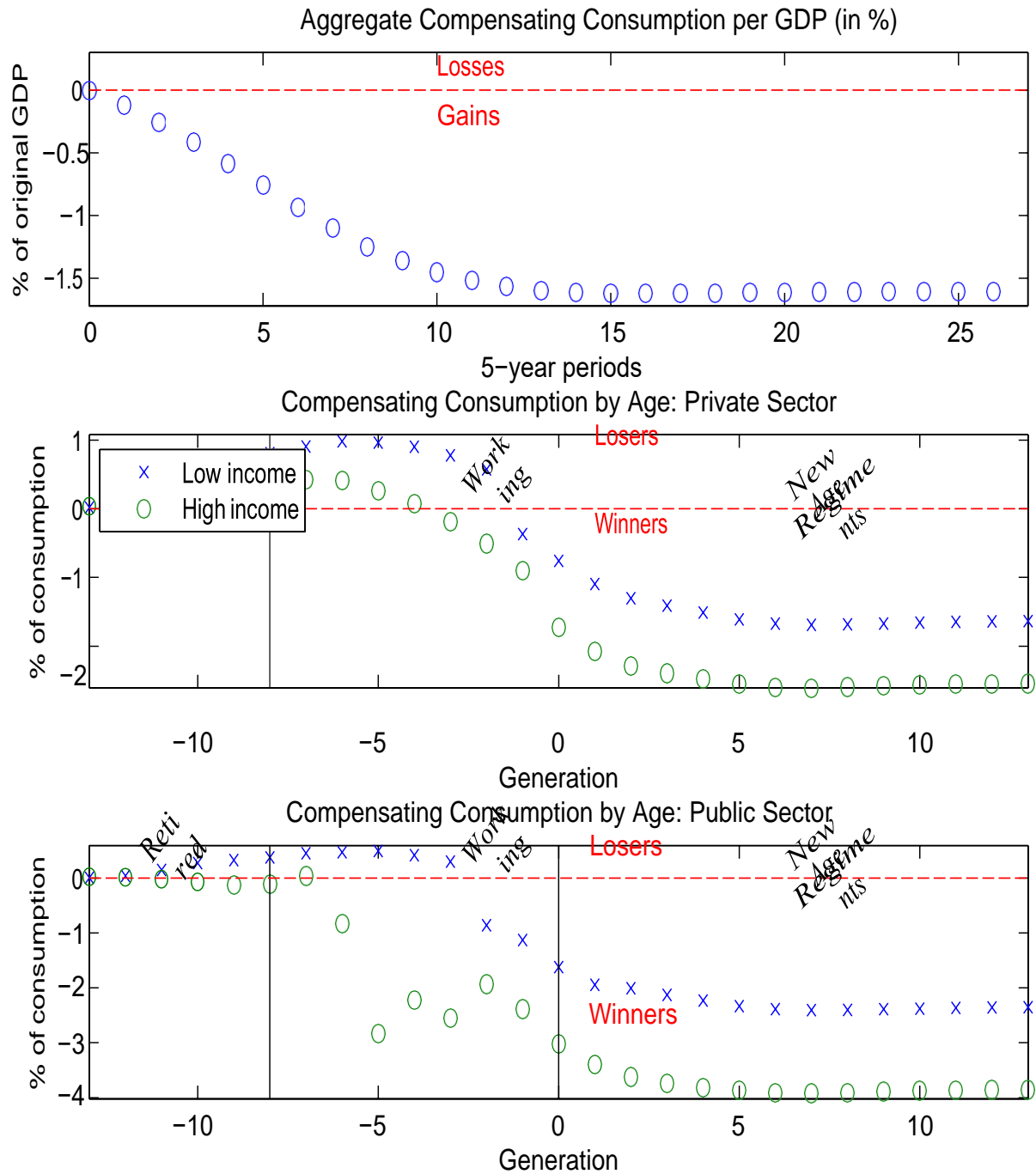


Figure 5: A Risk-Premium Shock, Debt Reduction and Welfare Dynamics. The government investment adjusts to accommodate the decrease of debt to to 85 percent of GDP and the risk premium shock.