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ABSTRACT

The question of what is a sustainable public debt is paramount in the macroeconomic analysis of fiscal policy. This question is usually posed as asking whether the outstanding public debt and its projected path are consistent with those of the government's revenues and expenditures (i.e. whether fiscal solvency conditions hold). We identify critical flaws in the traditional approach to evaluate debt sustainability, and examine three alternative approaches that provide useful econometric and model-simulation tools to analyze debt sustainability. The first approach is Bohn's non-structural empirical framework based on a fiscal reaction function that characterizes the dynamics of sustainable debt and primary balances. The second is a structural approach based on a calibrated dynamic general equilibrium framework with a fully specified fiscal sector, which we use to quantify the positive and normative effects of fiscal policies aimed at restoring fiscal solvency in response to changes in debt. The third approach deviates from the others in assuming that governments cannot commit to repay their domestic debt, and can thus optimally decide to default even if debt is sustainable in terms of fiscal solvency. We use these three approaches to analyze debt sustainability in the United States and Europe after the recent surge in public debt following the 2008 crisis, and find that all three raise serious questions.

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1 Introduction

The question of what is a sustainable public debt is paramount in the macroeconomic analysis of fiscal policy. The question is often understood as asking whether the government is solvent. That is, whether the outstanding stock of public debt matches the projected present discounted value of the primary fiscal balance, measuring both at the general government level and including all forms of fiscal revenue as well as all current expenditures, transfers and entitlement payments. This Chapter revisits the question of public debt sustainability, identifies critical flaws in traditional ways to approach it, and discusses three alternative approaches that provide useful econometric and model-simulation tools to evaluate debt sustainability.

The first approach is an empirical approach proposed in Bohn's seminal work on fiscal solvency. The advantage of this approach is that it provides a straigthforward and powerful method to conduct non-structural empirical tests that are sufficient to satisfy fiscal solvency. These tests require only data on the primary balance, outstanding debt and a few control variables. The data are then used to estimate linear and non-linear *fiscal reaction functions* (FRFs) which map the response of the primary balance to changes in outstanding debt, conditional on the control variables. A key lesson from Bohn's work is that testing for fiscal solvency per se is futile, because the intertemporal government budget constraint holds if the debt series satisfies the very weak requirement of being integrated of *any* finite order (see Bohn (2007)). In light of this result, he suggests that the focus should be on analyzing the dynamics of fiscal adjustment that mantain solvency (i.e. on the characertistics of the FRFs).

We provide new FRF estimation results for historical data spanning the 1791-2014 period for the United States, and for a cross-country panel of advanced and emerging economies for the period 1951-2013. The results are largely in line with previous findings showing that the hypothesis that the sufficiency condition for fiscal solvency of a linear FRF (a positive conditional response coefficient of the primary balance to outstanding debt) cannot be rejected. On the other hand, the results provide clear evidence of a structural shift in the response coefficients since the 2008 crisis, which is reflected in large negative residuals in the FRF since 2009. The primary balances predicted by the FRF of the United States for the period 2008-2014 are much larger than the observed ones, and the debt and primary balance dynamics that FRFs predict after 2014 for both the U.S. and European economies yield higher primary surpluses and lower debt ratios than what official projections show. Moreover, in the case of the United States, the pattern of consistent primary deficits since 2009 and continuing until at least 2020 in official projections, is unprecedented. In all previous episodes of increases in public debt of comparable magnitudes as in the Great Recession (the Civil War, the two World Wars and the Great Depression), the primary balance was in surplus five years after the debt peaked.

Using the estimated FRFs, we illustrate that there are multiple parameterizations of a FRF that support the same expected present discounted value of primary balances, and thus all of them make the same initial public debt position sustainable. However, these multiple reaction functions yield different short- and long-run dynamics of debt and primary balances, and therefore differ in terms of social welfare and their macro effects. At this point, this non-structural approach reaches its limits, because comparing across these different patterns of fiscal adjustment requires a structural framework that models explicitly the mechanisms and distortions by which tax and expenditure policies affect the economy, and the structure of financial markets the government can access.

The second approach to study debt sustainability that we examine picks up at this point. We use a calibrated two-country dynamic general equilibrium framework with a fully specified fiscal sector to study the effects of alternative fiscal strategies to restore fiscal solvency in the aftermath of large increases in debt. The model is calibrated to data from the United States and Europe and used to quantify the positive and normative effects of fiscal policies that can increase the present value of the primary fiscal balance by enough to match the increases in debt observed since 2008 (i.e. by enough to restore fiscal solvency). The framework has many of the standard elements of the workhorse open-economy Neoclassical model with exogenous long-run balanced growth, but it includes modifications designed to make the model consistent with the observed elasticity of tax bases. As a result, the model captures more accurately the relevant tradeoffs between revenue-generating capacity and distortionary effects in the choice of fiscal instruments.

The results show that indeed alternative fiscal policy strategies that are equivalent in that they all restore fiscal solvency, have very different effects on welfare and macro aggregates. Moreover, some fiscal policy setups fall short from producing the changes in the equilibrium present discounted value of primary balances that are necessary to match the observed increases in debt. This is particularly true for taxes on capital in the United States and labor taxes in Europe. The dynamic Laffer curves for these taxes peak below the level required to make the higher post-2008 debts sustainable.

We also find that, in line with findings in the international macroeconomics literature, the fact that the U.S. and Europe are financially-integrated economies implies that the revenue-generating capacity of taxation on capital income is adversely affected by international externalities. At the prevailing tax structures, increases in U.S. capital income taxes (assuming European taxes are constant) generate significantly smaller increases in the present value of U.S. primary balances than if the U.S. implemented the same taxes under financial autarky. The model also predicts that at its current capital tax rate, Europe is in the inefficient side of its dynamic Laffer curve for the capital income tax. Hence, lowering its tax, assuming the U.S. keeps its capital tax constant, induces externalities that enlarge European fiscal revenues, and thus the present value of European primary balances rises significantly more than if Europe implemented the same taxes under financial autarky.

Given the evidence of structural changes weakening the response of primary balances to debt post 2008, and the results suggesting that tax increases may not be able to generate enough revenue to restore fiscal solvency and are hampered by international externalities, the risk of default on domestic public debt must be considered. In addition, the ongoing European debt crisis and the recurrent turmoil around federal debt ceiling debates in the United States demonstrate that domestic public debt is not in fact the risk-free asset that is generally taken to be. The first two approaches to study debt sustainability that we discuss are not useful for addressing default risk on domestic debt, because they are built on the premise that the government is committed to repay. The risk here is not that of external sovereign default, which is the subject of a different Chapter in this Handbook and has been widely studied in the literature. Instead, the risk here is the one that Reinhart and Rogoff (2011) referred to as "the forgotten history of domestic debt:" Historically, there have been episodes in which governments have defaulted outright on their domestic public debt, and until very recently the macro literature had paid little attention to these episodes. Hence, the third approach we examine assumes that governments cannot commit to repay their domestic debt, and decide optimally to default even if standard solvency conditions hold, and even when domestic debt holders enter in the payoff function of the sovereign making the default decision. Sustainable debt in this setup is the debt that can be supported as a market equilibrium with positive quantity and price, exposed with positive probability to a government default, and with actual episodes in which default is the equilibrium outcome.

In this framework, the government maximizes a social welfare function that assigns positive weight to the welfare of all domestic agents in the economy, including those who are holders of government debt. Defaulting on public debt is useful as a tool for redistributing resources across agents, but is also costly because debt serves as a vehicle for tax-smoothing and self-insurance. A quantitative application of this setup calibrated to data from Europe shows how the tradeoff between these costs and benefits of default interact to determine the dynamics of sustainable debt. Default is an infrequent event, but it does occur with low probability and as a result returns on government debt exhibit periods in which they carry positive default premia.

The rest of this Chapter is organized as follows: Section 2 discusses the classic approach to evaluate debt sustainability and reviews Bohn's work on fiscal reaction functions, including the new estimation results. Section 3 focuses on the quantitative predictions of the two-country dynamic general equilibrium model for the positive and normative effects of fiscal policies aimed at restoring fiscal solvency in response to large increases in debt, including the application to the case of the United States and Europe. Section 4 covers the framework of optimal domestic sovereign default, with the quantitative example based on data from Europe.

2 Empirical Approach

Several articles and conference volumes survey the large literature on indicators of public debt sustainability and empirical tests of fiscal solvency (e.g. Buiter (1985); Blanchard (1990); Blanchard, Chouraqui, Hagemann, and Sartor (1990); Chalk and Hemming (2000); IMF (2003); Afonso (2005); Bohn (2008); Neck and Sturm (2008) and Escolano (2010)). These surveys generally start by formulating standard concepts of government accounting, and then build around them the arguments to construct indicators of debt sustainability or tests of fiscal solvency. We proceed here in a similar way, but adopting a general formulation following the analysis of government debt in the textbook by Ljungqvist and Sargent (2012). The advantage of this formulation is that it is explicit about the structure of asset markets, which as we show below turns out to be critical for the design of empirical tests of fiscal solvency.

Consider a simple economy in which output and total government outlays (i.e. current expenditures and transfer payemnts) are exogenous functions of a vector of random variables s denoted $y(s_t)$ and $g(s_t)$ respectively. The exogenous state vector follows a standard discrete Markov process with transition probability matrix $\pi(s_{t+1}, s_t)$. Taxes at date t depend on s_t and on the outstanding public debt, but since the latter is the result of the history of values of s up to and including date t, denoted s^t, taxes can be expressed as $\tau_t(s^t)$. In terms of asset markets, this economy has a full set of state-contingent Arrow securities with a j-step ahead equilibrium pricing kernel given by $Q_j(s_{t+j}|s_t) = MRS(c_{t+j}, c_t)\pi^j(s_{t+j}, s_t)$.[1]

Public debt outstanding at the beginning of date t is denoted as $b_{t-1}(s_t|s^{t-1})$, which is the amount of date-t goods that the government promised at $t-1$ to deliver if the economy is in state s_t at date t with history s^{t-1}. The government's budget constraint can then be written as follows:

$$\sum_{s_{t+1}} Q_1(s_{t+1}|s_t)b_t(s_{t+1}|s^t)\pi(s_{t+1}, s_t) - b_{t-1}(s_t|s^{t-1}) = g(s_t) - \tau_t(s^t).$$

Notice that there are no restrictions on what type of financial instruments the goverment uses to borrow. In particular, the typical case in which the goverment issues only risk-free debt is not ruled out. In this case, the above budget constraint reduces to the familiar form: $[b_t(s^t)/R_1(s_t)] - b_{t-1}(s^{t-1}) = g(s_t) - \tau_t(s^t)$, where $R_1(s_t)$ is the one-step-ahead risk-free real interest rate (which at equilibrium satisfies $R_1(s_t)^{-1} = E_t\left[MRS(c_{t+1}, c_t)\right]$).

Imposing the no-Ponzi game condition $\liminf_{j\to\infty} E_t[MRS(c_{t+j}, c_t)b_{t+j}] = 0$ on the above budget constraint, and using the equilibrium asset pricing conditions, yields the following intertemporal government budget constraint (IGBC):

$$b_{t-1} = pb_t + \sum_{j=1}^{\infty} E_t[MRS(c_{t+j}, c_t)pb_{t+j}], \tag{1}$$

where $pb_t \equiv \tau_t - g_t$ is the primary fiscal balance. This IGBC condition is the familiar fiscal solvency condition that anchors the standard concept of debt sustainability: b_{t-1} is said to be sustainable if it matches the

[1] $MRS(c_{t+j}, c_t) \equiv \beta^j u'(c(s_{t+j}))/u'(c(s_t))$ is the marginal rate of substitution in consumption between date $t+j$ and date t. Note also that in this simple economy the resource constraint implies that consumption is exogenous and given by $c(s_{t+j}) = y(s_{t+j}) - c(s_{t+j})$.

expected present discounted value of the stream of future primary fiscal balances. Hence, the two main goals of most of the empirical literature on public debt sustainability have been: (a) to construct simple indicators that can be used to assess debt sustaibability, and (b) to develop formal econometric tests that can determine whether the hypothesis that IGBC holds can be rejected by the data.

2.1 Classic Debt Sustainability Analysis

Classic public debt sustainability analysis focuses on the long-run implications of a deterministic version of the IGBC. This approach uses the government budget constraint evaluated at steady-state as a condition that relates the long-run primary fiscal balance as a share of GDP and the debt-output ratio, and defines the latter as the sustainable debt (see Buiter (1985), Blanchard (1990) and Blanchard, Chouraqui, Hagemann, and Sartor (1990)). To derive this condition from the setup described earlier, first remove uncertainty from the government budget constraint with non-state contingent debt to obtain: $[b_t/(1+r_t)]-b_{t-1} = -pb_t$. Then rewrite the equation with government bonds at face value instead of discount bonds: $b_t-(1+r_t)b_{t-1} = -pb_t$. Finally, apply a change of variables so that debt and primary balances are measured as GDP ratios, which implies that the effective interest rate becomes $r_t \equiv (1+i_t^r)/(1+\gamma_t)-1$, where i_t^r is the real interest rate and γ_t is the growth rate of GDP (or alternatively use the nominal interest rate and the growth rate of nominal GDP). Solving for the steady-state debt ratio yields:

$$b^{ss} = \frac{pb^{ss}}{r} \approx \frac{pb^{ss}}{i^r - \gamma}. \quad (2)$$

Thus, the steady-state debt ratio b^{ss} is the annuity value of the steady state primary balance pb^{ss}, discounted at the long-run, growth-adjusted interest rate. In policy applications, this condition is used either as an indicator of the primary balance-output ratio needed to stabilize a given debt-output ratio (the so-called "debt stabilizing" primary balance), or as an indicator of the sustainable target debt-output ratio that a given primary balance-output ratio can support. There are also variations of this approach that use the constraint $b_t - (1 + r_t)b_{t-1} = -pb_t$ to construct estimates of primary balance targets needed to produce desired changes in debt at shorter horizons than the steady state. For instance, imposing the condition that the debt must decline ($b_t - b_{t-1} < 0$), implies that the primary balance must yield a surplus that is at least as large as the growth-adjusted debt service: $pb_t \geq r_t b_{t-1}$.

The main flaw of approaching debt sustainability in this way is that it only *defines* what long-run debt is for a given long-run primary balance (or vice versa) if stationarity holds, or *defines* lower bounds on the short-run dynamics of the primary balance. It does not actually connect the outstanding initial debt of a particular period b_{t-1} with b^{ss}, where the latter should be $\lim_{j\to\infty} b_{t+j}$ starting from b_{t-1}, and thus it cannot actually guarantee that b_{t-1} is sustainable in the sense of satisfying the IGBC. In fact, as we show below, for a given b_{t-1} there are multiple dynamic paths of the primary balance that satisfy IGBC. A subset of these paths converges to stationary debt positions, with different values of b^{ss} that vary widely depending on the primary balance dynamics, and there is also a subset of these paths for which the debt diverges to infinity but is still consistent with IGBC!

A second important flaw of this approach is the absence of uncertainty and considerations about the asset market structure. The implications of adding these features are easy to illustrate using the debt sustainaibility setup proposed by Mendoza and Oviedo (2006, 2009), in which the government issues non-state contingent debt facing stochastic Markov processes for government revenues and outlays. The key assumption of their setup is that the goverment is committed to repay, which imposes a constraint on public debt akin to Ayagari's Natural Debt Limit for private debt in the Bewley models of heterogeneous agents with incomplete markets.

Following the simple version of this framework presented in Mendoza and Oviedo (2009), assume that output follows a deterministic trend, with an exogenous growth rate given by γ, and that the real interest rate is constant. Assume also that the goverment keeps its outlays smooth, unless it finds itself unable to borrow and when this happens it cuts its outlays to minimum tolerable levels.[2] Since the government cannot have its outlays fall below this minimum level, it does not hold more debt than the amount it could service after a long history in which $pb(s^t)$ remains at its worst possible realization (i.e. the primary balance obtained with the worst realization of revenues, $\tau^{\min}$, and public outlays at their tolerable minimum $g^{\min}$), which can happen with positive probability. This situation is defined as a state of fiscal crisis and it sets and upper bound on debt denoted the "Natural Public Debt Limit" (NPDL), which is given by the growth-adjusted annuity value of the primary balance in the state of fiscal crisis:

$$b_t \leq NPDL \equiv \frac{\tau^{\min} - g^{\min}}{i^r - \gamma}. \tag{3}$$

This result together with the government budget constraint yields a law of motion for debt that follows this simple rule: $b_t = \max[NPDL, (1+r_t)b_{t-1} - pb_t] \geq \bar{b}$, where $\bar{b}$ is an assumed lower bound for debt that can be set to zero for simplicity (i.e. the government cannot become a net creditor).

Notice that NPDL is lower for governments that have (a) higher variability in public revenues (i.e. lower $\tau^{\min}$ in the support of the Markov process of revenues), (b) less flexibility to adjust public outlays (higher $g^{\min}$), or (c) lower growth rates and/or higher real interest rates. The contrast between NPDL and b^{ss} from the classic debt sustainability analysis is also important to note. The expressions are similar, but the two methods yield sharply different implications for debt sustainability: The classic approach will always identify as sustainable debt ratios that are unsustainable according to the NPDL, because in practice b^{ss} uses the average primary fiscal balance, instead of its worst realization, and as a result it yields a long-run debt ratio that violates the NPDL. Moreover, while b^{ss} cannot be related to the IGBC, the debt rule $b_t = \max[NPDL, (1+r_t)b_{t-1} - pb_t] \geq \bar{b}$ always satisfies the IGBC, because debt is bounded above at the NPDL, which guarantees that the no-Ponzi game condition cannot be violated.

The NPDL can be turned into a policy indicator by characterizing the probabilistic processes of the components of the primary balance together with some simplifying assumptions. On the revenue side, the probabilistic process of tax revenues reflects the uncertainty affecting tax rates and tax bases. This uncertainty includes domestic tax policy variability, the endogenous response of the economy to that variability, and other factors that can be largely exogenous to the domestic economy (e.g. the effects of fluctuations in commodity prices and commodity exports on government revenues). On the expenditure side, government expenditures adjust partly in response to policy decisions, but the manner in which they respond varies widely across countries, as the literature on procyclical fiscal policy in emerging economies has shown (e.g. see Alesina and Tabellini (2005), Kaminsky, Reinhart, and Vegh (2005), Talvi and Vegh (2005)).

The quantitative analysis in Mendoza and Oviedo (2009) treats the revenue and expenditures processes as exogenous, and calibrates them to 1990-2005 data from four Latin American economies.[3]Since the value of the expenditure cuts that each country can commit to is unosbervable, they calculate instead the implied cuts in government outlays, relative to each country's average (i.e. $g^{\min} - E[g]$), that would be needed so that each country's NPDL is consistent with the largest debt ratio observed in the sample. The largest debt ratios are around 55 percent for all four countries (Brazil, Colombia, Costa Rica and Mexico), but the cuts in outlays that make these debt ratios consistent with the NPDL range from 3.8 percentage points of GDP for Costa Rica to 6.2 percentage points for Brazil. This is the case largely because revenues in Brazil have a coefficient of variation of 12.8 percent, v. 7 percent in Costa Rica, and hence to support a similar NPDL at

[2] This is a useful assumption to keep the setup simple, but is not critical. Mendoza and Oviedo (2006) model government expenditures entering a CRRA utility function as an optimal decision of the government, and here the curvature of the utility function imposes the debt limit in the same way as in Bewley models.

[3] Mendoza and Oviedo (2006) endogenize the choice of government outlays and decentralize the private and public borrowing decisions in a small open economy model with non-state-contingent assets.

a much higher revenue volatility requires higher $g^{\min}$. Mendoza and Oviedo also showed that the time-series dynamics of debt follow a random walk with boundaries at NPDL and $\bar{b}$.

2.2 Bohn's Debt Sustainability Framework

In a series of influential articles published between 1995 and 2011, Henning Bohn made four major contributions to the empirical literature on debt sustainability tests:

1. *IGBC tests that discount future primary balances at the risk-free rates are mispecified, because the correct discount factors are determined by the state-contingent equilibriun pricing kernel (Bohn, 1995).* Tests affected by this problem include those reported in several well-known empirical studies (e.g. Hamilton and Flavin (1986), Hansen, Roberds, and Sargent (1991), and Gali (1991)). Following Ljungqvist and Sargent (2012), this mispecification error is easy to illutrate by using the equilibrium risk-free rates ($R^{-1}_{t+j} = E_t\left[MRS(c_{t+j}, c_t)\right]$) to rewrite the IGBC as follows:

$$b_{t-1} = pb_t + \sum_{j=1}^{\infty}\left[\frac{E_t[pb_{t+j}]}{R_{t+j}} + cov_t\left(MRS(c_{t+j}, c_t), pb_{t+j}\right)\right]. \tag{4}$$

   Hence, discounting the primary balances at the risk-free rates is only correct if

$$\sum_{j=1}^{\infty} cov_t\left(MRS(c_{t+j}, c_t), pb_{t+j}\right) = 0.$$

   This would be true under one of the following assumptions: (a) perfect foresight, (b) risk-neutral private agents, or (c) primary fiscal balances that are uncorrelated with future marginal utilities of consumption. All of these assumptions are unrealistic, and (c) in particular runs contrary to the strong empirical evidence showing that primary balances are not only correlated with macro fluctuations, but show a strikingly distinct pattern across industrial and developing countries: primary balances are procyclical in industrial countries, and acyclical or countercyclical in developing countries. Moreover, Bohn (1995) also showed examples in which this mispecification error leads to incorrect inferences that reject fiscal solvency when it actually does hold. For instance, a rule that maintains g/y and b/y constant in a balanced-growth economy with i.i.d. output growth violates the mispeficied IGBC if mean output growth is greater or equal than the interest rate, but it does satisfy condition (1).

2. *Testing for debt sustainability is futile, because the IGBC holds under very weak conditions. The IGBC holds if either debt or revenue and spending inclusive of debt service are integrated of finite but arbitrarily high order (Bohn, 2007).* This invalidates several fiscal solvency tests based on specific stationarity and co-integration conditions (e.g. Hamilton and Flavin (1986), Trehan and Walsh (1988), Quintos (1995)), because neither a particular order of integration of the debt data, nor the co-integration of revenues and government outlays is necessary for debt sustainability. As Bohn explains in the proof of this result, the reason is intuitive: In the forward conditional expectation that forms the no-Ponzi game condition, the j^{th} power of the discount factor asymptotically dominates the expectation $E_t(b_{t+j})$ as $j \to \infty$ if the debt is integrated of any finite order. This occurs because $E_t(b_{t+j})$ is *at most* a polynomial of order n if b is integrated of order n, while the discount factor is exponential in j, and exponential growth dominates polynomial growth. But perhaps of even more significance is the implication that, since integration of finite order is indeed a very weak condition, testing for fiscal solvency or debt sustainability per se is futile: The data are all but certain to reject the hypotheses that debt or revenue and spending inclusive of debt service are non-stationary after differencing the data a finite number of times (usually only once!). Bohn (2007) concluded that, in light of this result, using econometric tools

to try and identify in the data fiscal reaction functions that support fiscal solvency and studying their dynamics is "more promising for understanding deficit problems."

3. *A linear fiscal reaction function (FRF) with a statistically significant, positive (conditional) response of the primary balance to outstanding debt is sufficient for the IGBC to hold (Bohn (1998, 2008)).* Proposition 1 in Bohn (2008) demonstrates that this linear FRF is sufficient to satisfy the IGBC:

$$pb_t = \mu_t + \rho b_{t-1} + \varepsilon_t,$$

for all t, where $\rho > 0$, μ_t is a set of additional determinants of the primary balance, which typically include an intercept and proxies for temporary fluctuations in output and government expenditures, and ε_t is i.i.d. The proof only requires that μ_t be bounded and that the present value of GDP be finite. Intuitively, the argument of the proof is that with pb changing by the positive factor ρ when debt rises, the growth of the debt j periods ahead is lowered by $(1-\rho)^j$. Formally, for any small $\rho > 0$, the following holds as $j \to \infty$: $E_t[MRS(c_{t+j}, c_t)b_{t+j}] \approx (1-\rho)^j b_t \to 0$, which in turn implies that the NPG condition and thus the IGBC hold. Note also that while debt sustainability holds for any $\rho > 0$, the long-run behavior of the debt ratio differs sharply depending on the relative values of the mean r and ρ. To see why, combine the FRF and the government budget constraint to obtain the law of motion of the debt ratio $b_t = -\mu_t + (1 + r_t - \rho)b_{t-1} + \varepsilon_t$. Hence, debt is stationary only if $\rho > r$, otherwise it explodes, but as long as $\rho > 0$ it does so at a slow enough pace to still satisfy IGBC.[4] In addition, the IGBC holds for the same value of initial debt for any $\rho > 0$, but, if $\rho > r$, debt converges to a higher long-run average as ρ falls. These results also show why the steady-state debt b^{ss} of the classic debt sustainability analysis is not useful for assessing debt sustainability: With the linear FRF, multiple well-defined long-run averages of debt are consistent with debt sustainability if $\rho > r$, and even exploding debt is consistent with debt sustainability if $0 < \rho < r$. Moreover, in the limit as $r \to 0$, the classic analysis predicts that debt diverges to infinity ($b^{ss} \to \infty$ if pb^{ss} is finite), while the linear FRF predicts that both b and pb converge to well-defined long-run averages given by $-\mu/\rho$ and 0.

4. *Empirical tests of the linear FRF based on historical U.S. data and various subsamples cannot reject the hypothesis that IGBC holds (Bohn (1998, 2008)).* In his 2008 article, Bohn constructed a dataset going back to 1791, the start of U.S. public debt after the Funding Act of 1790, and found that the response coefficient estimated with 1793-2003 data is positive and significant, ranging from 0.1 to 0.12. Moreover, looking deeper into the fiscal dynamics he found that economic growth has been sufficient to cover the entire servicing costs of U.S. public debt, but there are structural breaks in the response coefficient. The 1793-2003 estimates are about twice as large as those obtained in Bohn (1998) using data for 1916-2005, which is a period that emphasizes the cold-war era of declining debt but high military spending.

Bohn's framework has been applied to cross-country datasets by Mendoza and Ostry (2008a) and extended to include a non-linear specification allowing for default risk by Ghosh, Kim, Mendoza, Ostry et al. (2013a).[5] Mendoza and Ostry found estimates of response coefficients for a panel of industrial countries that are similar to those Bohn (1998) obtained for the United States. In addition, they found that the solvency condition holds for a panel that includes both industrial and developing countries, as well as in a sub-panel that includes only the latter. They also found, however, that cross-sectional breaks are present in the data at particular debt thresholds. In the combined panel and the sub-panels with only advanced or only developing economies, there are high-debt country groups for which the response coefficient is not

[4] Bohn (2007) shows that this result holds for either of the following three assumptions about the interest rate process: (i) $r_t = r$ for all t, (ii) r_t is a stochastic process that is serially uncorrelated with $E_t[r_{t+1}] = r$, or (iii) r_t is any stochastic process with mean r subject only to implicit restrictions such that $b_t = \frac{1}{1+r} E_t[pb_{t+1} + b_{t+1} - (r_{t+1} - r)b_t]$.

[5] The same approach has also been used to test for external solvency (i.e. whether the present discounted value of the balance of trade matches the observed net foreign asset position). Durdu, Mendoza, and Terrones (2013) conducted cross-country empirical tests using data for 50 countries over the 1970-2006 period and found that the data cannot reject the hypothesis of external solvency, which in this case is measured as a negative response of net exports to net foreign assets.

statistically significantly different from zero. Ghosh et al. found that the response coefficients fall sharply at high debt levels, and obtained estimates of fiscal space that measure the distance between observed debt ratios and the largest debt ratios that can be supported given debt limits implied by the presence of default risk.

2.3 Estimated Fiscal Reaction Functions and their Implications

We provide below new estimation results for linear FRFs for the United States using historical data from 1791 to 2014, and for a cross-country panel using data for the 1951-2013 period. Some of the results are in line with the findings of previous studies, but the key difference is that there is a significant break in the response of the primary balance to debt after the 2008. We then use the estimation results and the historical data to put in perspective the current fiscal situation of the United States and Europe. In particular, we show that: (a) primary balance adjustment in the United States is lagging significantly behind what has been observed in the aftermath of previous episodes of large increases in debt, (b) observed primary deficits have been much larger than what the FRFs predict, and (c) hypotethical scenarios with alternative response coefficients produce sharply different patterns of transitional dynamics and long-run debt ratios, but they are all consistent with the same observed initial debt ratios (i.e. IGBC holds for all of them).

(a) FRF Estimation Results

Table 1 shows estimation results for the FRF of the United States using historical data for the 1791-2014 period. The Table shows results for five regression models similar to those estimated in Bohn (1998, 2008). Column (1) shows the base model, which uses as regressors the initial debt ratio, the cyclical component of output, and military expenditures (i.e. the sum of expenditures by the Department of Defense and the Veterans Administration) as a measure of transitory fluctuations in government expenditures. Column (2) introduces a non-linear spline coefficient when the debt is higher than the mean. Column (3) introduces an AR(1) error term. Column (4) adds the squared mean deviation of the debt ratio. Column (5) includes a time trend. Columns (6) and (7) provide modifications that are important for showing the structural instability of the FRF post-2008: Column (6) re-runs the base model truncating the sample in last year of the sample used in Bohn (2008) and Column (7) uses a sample that ends in 2008. The signs of the debt, output gap and military expenditures coefficients are the same as in Bohn's regressions, and in particular the response coefficient estimates are generally positive, which satisfies the sufficiency condition for debt sustainability.

In Columns (1)-(5), the point estimates of ρ range between 0.077 and 0.105, which are lower than Bohn's (2008) estimates based on 1793-2003 data, but higher than his (1998) estimates based on 1916-1995 data. The ρ estimates are always statistically significant, although only at the 90-percent confidence level in the base and squared-debt models.

Column (6) shows that if we run the linear FRF over the same sample period as in Bohn (2008), the results are similar to his.[6] The point estimate of ρ is 0.105, compared with 0.121 in Bohn's study (both statistically significant at the 99 percent confidence level). But in the base model in Column (1) we found that using the full sample up to 2014 the point estimate of ρ falls to 0.078. Moreover, excluding the post-2008-crisis data in Column (7), the results are very similar to those obtained with the same sample period as Bohn's. Hence, these results suggest that the addition of the post-2008 data, a tumultous period in the fiscal stance of the United States, produces a structural shift in the FRF.[7] Testing formally for this hypothesis, we

[6] They differ because we use a different measure of military expenditures, and measure cyclical GDP as deviations from HP trend instead of an AR(2) process.

[7] Bohn (2008) also found evidence of structural shifts when contrasting his results for 1784-2003 with his 1916-1995 results, with sharply lower response coefficients for the shorther sample, which he attributed to the larger weight of the cold-war era

found that Chow's forecast test rejects strongly the null hypothesis of no structural change in the value of ρ when the post-2008 data are added. Hence, the decline in the estimate of ρ from 0.102 to 0.078 is statistically significant. This change in the response of the primary balance to higher debt ratios may seem small, but it implies that the primary balance adjustment is about 25 percent smaller, and as we show later this results in large changes in the short- and long-run dynamics of debt.

The regressions with nonlinear features (Column (2) with the debt spline at the mean debt ratio, and Column (4) with the squared deviation from the mean debt ratio) are very different from Bohn's estimates. In Bohn (1998), the FRF with the same spline term has a negative point estimate ρ=-0.015 and a large, positive spline coefficient of 0.105 when debt is above its mean, so that for above-average debt ratios the response of the primary balance is stronger than for below-average debt ratios, and becomes positive with a net effect of 0.09, which is consistent with debt sustainability. In contrast, Table 1 shows a ρ estimate of 0.09 with a spline coefficient of -0.14. Hence, these results suggest that the response of the primary balance is weaker for above-average debt ratios, and the net effect is negative at -0.05, which violates the linear FRF's sufficiency condition for debt sustainability. The spline coefficient is not, however, statistically significant. For the squared-debt regressions, Bohn (2008) estimated a positive coefficient of 0.02, while the coefficient shown in Table 1 is only 0.003 (both not statistically significant). Thus, both the debt-spline and debt-squared regressions are also consistent with the possibility of a structural change in the FRF. In particular, the stronger primary balance response at higher debt ratios that Bohn identified in his 1998 and 2008 studies changed to a much weaker response once the data up to 2014 are introduced. The rationale for this is that the large debt increases since 2008 have been accompanied by adjustments in the primary balance that differ sharply from what has been observed in previous episodes of large debt increases, as we illustrate below.

Tables 2–4 show the results of cross-country panel regressions similar to those reported by Mendoza and Ostry (2008b) and Ghosh, Kim, Mendoza, Ostry et al. (2013b), but expanded to include data for the 1951-2013 period for 25 advanced and 33 emerging economies. The first six result columns of these tables show results for three pairs of regression models. Each pair uses a different measure of government expenditures, since the measure based on military expenditures used in the U.S. regressions is unavailable and/or less relevant as a measure of the temporary component of government expenditures in the international dataset. Models (1) and (2) use total real government outlays (i.e. current expenditures plus all other non-interest expenditures, including transfer payments), models (3) and (4) use the cyclical component of total real outlays, and models (5) and (6) follow Mendoza and Ostry (2008) and use the cyclical component of real government absorption from the national accounts (i.e. real current government expenditures). Models (1), (3) and (5) include country-specific AR(1) terms, which Mendoza and Ostry also found important to consider, while model (2), (4) and (6) do not.

Table 2 shows that, as in Mendoza and Ostry, considering the country-specific AR(1) terms in the cross-country panel is important. The advanced economies' response coefficients are higher and with significantly smaller standard errors when the autocorrelation of error terms is corrected. Hence, we focus the rest of the discussion of the panel results on the results with AR(1) terms.

The advanced economies' response coefficients of the primary balance on debt in the AR(1) models are positive and statistically significant in general. The coefficients are smaller in the regressions that use cyclical components of either total outlays or current expenditures (models (3) and (5)) than in the one that uses the level of government outlays (model (1)), but across the first two the ρ coefficients are similar (0.02 v. 0.028). Following again Mendoza and Ostry, we focus on the regressions that use the cyclical components of current government expenditures.

Comparing the FRFs with country AR(1) terms and using the cyclical component of current government

(in which debt declined while military spending remained high).

expenditures across the three panel datasets, Tables 2–4 show that the estimates of ρ are 0.028 for advanced economies, 0.053 for emerging economies, and 0.047 for the combined panel. Mendoza and Ostry obtained estimates of 0.02 for advanced economies and 0.036 for both emerging economies and the combined panel. The results are somewhat different, but the two are consistent in producing larger values of ρ for emerging economies and the combined panel than for advanced economies.

The difference in the response coefficients across advanced and emerging economies highlights important features of their debt dynamics. Condition (4) suggests that countries with procyclical fiscal policy (i.e. acyclical or countercyclical primary balances) can sustain higher debt ratios than countries with countercyclical fiscal policy (i.e. procyclical primary balances). Yet we observe the opposite in the data: Advanced economies conduct countercyclical fiscal policy and show higher average debt ratios than emerging economies, which display procyclical or acyclical fiscal policy (i.e. significantly lower primary balance-output gap correlations). Indeed, the higher ρ of the emerging economies implies that these countries converge to lower mean debt ratios in the long run. As Mendoza and Ostry (2008b) concluded, this higher ρ is not an indicator of "more sustainable" fiscal policies in emerging economies, but evidence of the fact that past increases in debt of a given magnitude in these countries require a stronger conditional response of the primary balance, and hence less reliance on debt markets, than in advanced economies.

(b) Implications for Europe and the United States

Public debt and fiscal deficits rose sharply in several advanced economies after the 2008 global financial crisis, in response to both expansionary fiscal policies and policies aimed at stabilizing financial systems. To put in perspective the magnitude of this recent surge in debt, it is useful to examine Bohn's historical dataset of public debt and primary balances for the United States. Definining a public debt crisis as a year-on-year increase in the public debt ratio larger than twice the historical standard deviation, which is equivalent to more than 8.15 percentage points in Bohn's dataset, we identify five debt crisis events (see Figure 1): The two world wars (World War I with an increase of 28.7 percentage points of GDP over 1918-1919 and World War II with 59.3 percentage points over 1943-1945), the Civil War (19.7 percentage points over 1862-1863), the Great Depression (18.5 percentage points over 1932-1933), and the Great Recession (22.3 percentage points over 2009-2010). The Great Recession episode is the third largest, ahead of the Civil War and the Great Depression episodes.

Figure 1: United States Government Debt as Percentage of GDP

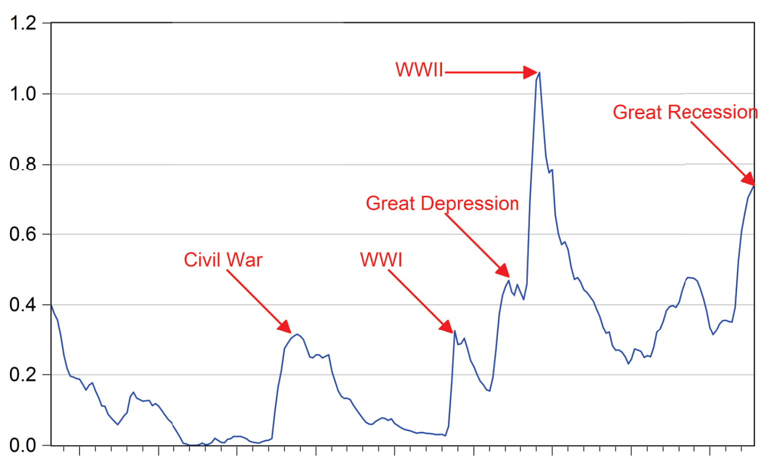
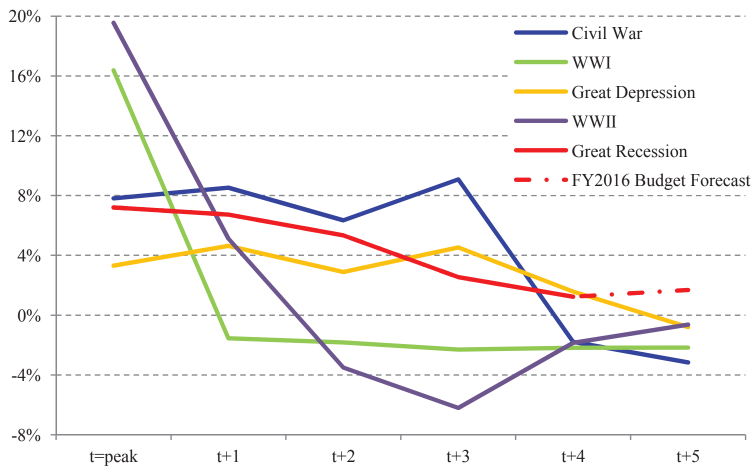


Figure 2 illustrates the short-run dynamics of the U.S. primary fiscal balance after each of the five debt crises. Each crisis started with large deficits, ranging from 4 percent of GDP for the Great Depression to nearly 20 percent of GDP for World War II, but the Great Recession episode is unique in that the primary balance remains in deficit four years after the crisis. In the three war-related crises, a large primary deficit turned into a small surplus within three years. By contrast, the latest baseline scenario from the Congressional Budget Office (*Updated Budget and Economic Outlook: 2015 to 2025*, January 2015), projects that the U.S. primary balance will continue in deficit for the next 10 years. The primary deficit is projected to shrink to 0.6 percent of GDP in 2018 and then hover near 1 percent through 2025. In addition, relative to the Great Depression, the first three deficits of the Great Recession were nearly twice as large, and by five years after the debt crisis of the Great Depression the United States had a primary surplus of nearly 1 percent of GDP. In summary, the post-2008 increase in public debt has been of historic proportions, and the absence of primary surpluses in both the four years after the surge in debt and the projections for 2015-2025 is *unprecedented* in U.S. history.

Figure 2: Government Deficit Response after Critical Events

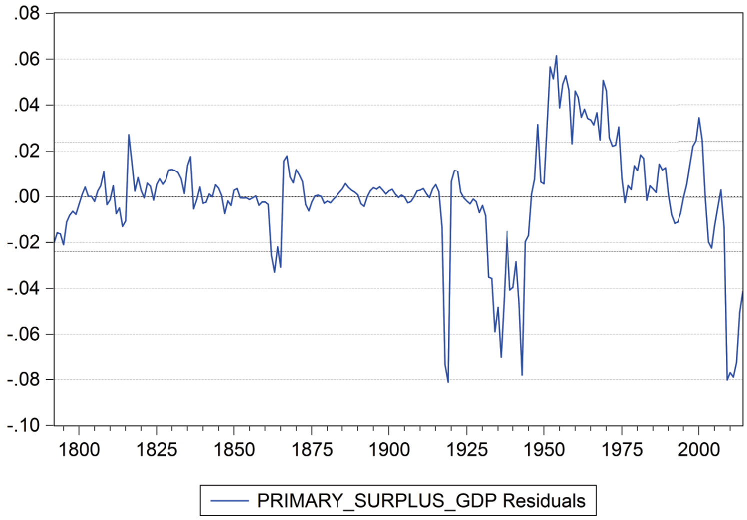


Many advanced European economies have not fared much better. Weighted by GDP, the average public debt ratio of the 15 largest European economies rose from 38 perecent to 58 percent between 2007 and 2011. The increase was particularly large in the five countries at the center of the European debt crisis (Greece, Ireland, Italy, Portugal and Spain), where the debt ratio weighted by GDP rose from 75 to 105 percent, but even in some of the largest European economies public debt rose sharply (by 33 and 27 percentage points in the United Kingdom and France respectively).

The estimated FRFs can be used to examine the implications of these rapid increases in public debt ratios for debt sustainability and for the short- and long-run dynamics of debt and deficits. Consider first the regression residuals. Figure 3 shows the residuals of the U.S. fiscal reaction function estimated in the base model (1) of Table 1, and Figure 4 shows rolling residuals from the same regression. These two plots show that the residuals for 2008-2014 are significantly negative, and much larger in absolute value than the residuals in the rest of the sample period. In fact, the residuals for 2009-2011 are twice as large as the corresponding minus-two-standard-error bound. Thus, the primary deficits observed during the post-2008 years have been much larger than what the FRFs predicted, even after accounting for the larger deficits that the FRFs allow on account of the depth of the recession and expansionary government expenditures. These large residuals are of course consistent with the results documented earlier showing evidence of structural change in the FRF when the post-2008 data are added.

The structural change in the FRF can also be illustrated by comparing the actual primary balances from 2009 to 2014 and the government-projected primary balances for 2015 to 2020 in the *President's Budget for Fiscal Year 2016* with the out-of-sample forecast that the FRF estimated with data up to 2008 in Column

Figure 3: Residuals for the US Fiscal Reaction Function



Note: This residuals correspond to the Base Model (1) in table 1. The dotted lines are at two s.d. above and below zero.

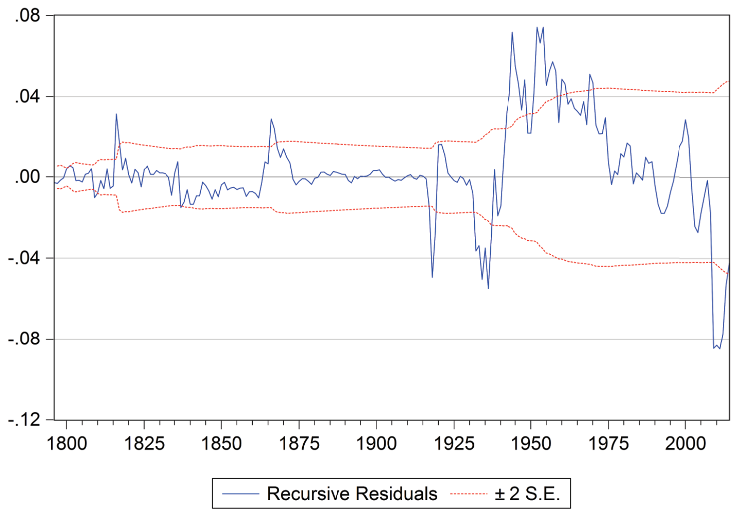
(7) of Table 1 produces (see Figure 5). To construct this forecast, we use the observed realizations of the cyclical components of output and government expenditures from 2009 to 2014, and for 2015 to 2020 we use again data from the projections in the *President's Budget*.

As Figure 5 shows, for the period 2009-2014, the primary balance reported deficits siginficantly larger than what the FRF predicted, and even larger than the deficit at the minus-two-standard-error bound of the forecast band. The mean forecast of the FRF predicted a rising primary surplus from zero to about 4 percent of GDP between 2009 and 2014, while the data showed deficits narrowing from 8 to about 2 percent of GDP.

The estimated FRF results can also be used to study projected time-series paths for public debt and the primary balance as of the latest actual observations (2014). To simulate the debt dynamics, we use the law of motion for public debt that results from combining the government budget constraint and the FRF mentioned earlier: $b_t = -\mu_t + (1 + r_t - \rho)b_{t-1} + \varepsilon_t$. We consider baseline scenarios in which we use estimated ρ coefficients for Europe and the United States, and simulate forward starting from the 2014 observations. For the United States, we used model (3) in table 1. For Europe, we use model (5) from table 2 and take a simple cross-section average among European industrialized countries. Projections of the future values of the fluctuations in output and government expenditures are generated with simple univariate AR models. In addition, we compare these baseline projection scenarios with scenarios in which we lower the response coefficient to half of the regression estimates or lower the intercept of the FRFs. Recall from the earlier discussion that changing these parameters, as long as $\rho > 0$, generates the same present discounted value of the primary balance as the baseline scenarios, but as we show below the transitional dynamics and long-run debt ratios they produce are very different. These simulations also require assumptions about the values of the real interest rate and the growth rate that determine $1 + r$. For simplicity, we assume that $r = 0$, which rules out the range in which debt can grown infinitely large but still be consistent with the IGBC (i.e. the range $0 < \rho < r$), and it also implies that primary balances converge to zero in the long run.[8]

[8] Real interest rates on government debt and rates of output growth in large industrial countries are low but with expectations of an eventual increase. Rather than taking a stance on the difference between the two, we just assumed here that they are equal.

Figure 4: Rolling residuals for the US Fiscal Reaction Function



Note: For each sample 1791-t the baseline specification, model (1) in table 1, is estimated and the residual at time t is reported together with the 2 standard deviation band for the errors in that sample.

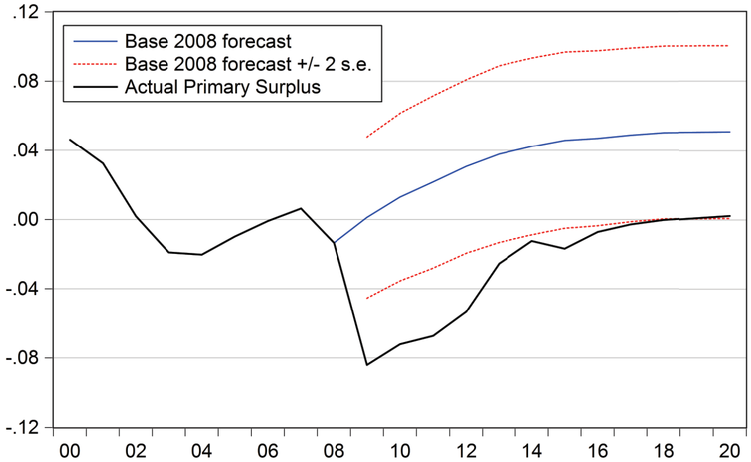
Figures 6 and 7 show the projected paths of debt ratios and primary balances for the baseline and the alternative scenarios, for both the United States and Europe. These plots show that under the baseline scenario the countries should be reporting primary surpluses that will decline monotonically over time, and should therefore display a monotonically declining path for the debt ratio converging back to the average observed in the sample period of the FRF estimates. With lower ρ or lower intercept, the initial surpluses can be significantly smaller or even turned into deficits, but the long-run mean debt ratio would increase significantly. In the case of the United Sates, for example, the long-run average of the debt ratio would rise from 29 percent in the baseline case to around 57 percent in the scenario with lower ρ.

All the debt and primary balance paths shown in Figures 6–7 satisfy the same IGBC, and therefore make the same initial debt ratio sustainable, but clearly their macroeconomic implications cannot be the same. Unfortunately, at this point the FRF approach reaches its limits. To evaluate the positive and normative implications of alternative paths of fiscal adjustment, we need a structural framework that can be used to quantify the implications of particular revenue and expenditure policies for equilibrium allocations and prices and for social welfare.

3 Structural Approach

This Section presents a two-country dynamic general equilibirum framework of fiscal adjustment, and uses it to quantify the positive and normative effects of alternative fiscal policy strategies to restore fiscal solvency (i.e. maintain debt sustainability) in the United States and Europe after the recent surge in public debt ratios. The structure of the model is similar to the Neoclassical models widely studied in the large quantitative literature on optimal taxation, the effects of tax reforms, and international tax competition (see, for example, Lucas (1990), Chari, Christiano, and Kehoe (1994), Cooley and Hansen (1992), Mendoza and Tesar (1998, 2005), Prescott (2004), Trabandt and Uhlig (2011), etc.). In particular, we use the two-country model proposed by Mendoza, Tesar, and Zhang (2014), which introduces modifications to the Neoclassical model that allow it to match empirical estimates of the elasticity of tax bases to change in tax rates. This is done

Figure 5: US Primary Surplus Actual Value and 2008 Based Forecast



Note: The forecast is based on model (7) in table 1 which has the sample restricted to 1791-2008. Given actual values of Debt-to-GDP ratio, GDP gap and Military Expenditure a forecast of the Primary Surplus to GDP ratio is generated for the sample 2009-2020. Actual variables from 2015 onwards correspond to estimates included in The President's Budget for Fiscal Year 2016. Chow's forecast test rejects the null hypothesis of no structural change starting in 2009 with 99.9% confidence.

by introducing endogenous capacity utilization and by limiting the tax allowance for depreciation of physical capital to approximate the allowance reflected in the data.[9]

3.1 Dynamic Equilibrium Model

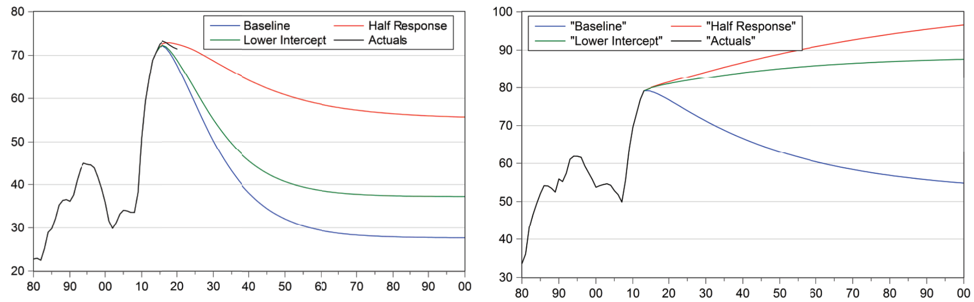
Consider a world economy that consists of two countries or regions: home (H) and foreign (F). Each country is inhabited by an infinitely-lived representative household, and has a representative firm that produces a single tradable good using as inputs labor, l, and units of utilized capital, $\tilde{k} = mk$ (where k is installed physical capital and m is the utilization rate). Capital and labor are immobile across countries, but the countries are perfectly integrated in goods and asset markets. Trade in assets is limited to one-period discount bonds denoted b and sold at a price q. Note that assuming this simple asset-market structure is without loss of generality, because the model is deterministic.

Following King, Plosser, and Rebelo (1988), growth is exogenous and driven by labor-augmenting technological change that occurs at a rate γ. Accordingly, stationarity of all variables (except labor and leisure) is induced by dividing them by the level of this technological factor.[10] The stationarity-inducing transformation of the model also requires discounting utility flows at the rate $\tilde{\beta} = \beta(1+\gamma)^{1-\sigma}$, where β is the standard subjective discount factor and σ is the coefficient of relative risk aversion of CRRA preferences, and adjusting the laws of motion of k and b so that the date-$t+1$ stocks grow by the balanced-growth factor $1+\gamma$.

[9] Dynamic models of taxation that consider endogenous capacity utilization include the theoretical analysis of optimal capital income taxes by Ferraro (2010) and the quantitative analysis of the effects of taxes in an RBC model by Greenwood and Huffman (1991).

[10] The assumption that growth is exogenous implies that tax policies do not affect long-run growth, in line with the empirical findings of Mendoza, Milesi-Ferretti, and Asea (1997).

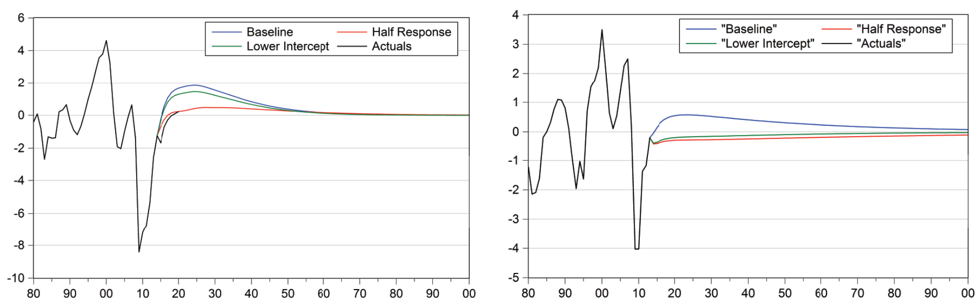
Figure 6: Debt-to-GDP Actuals and Simulations since 2014



(a) US debt to GDP (b) Europe debt to GDP

Note: For the US: Model (3) in table 1 is used in conjunction with estimated AR(2) processes for the output gap and military expenditure, plus the government budget constraint. For Europe: Model (5) in table 2 is used in conjunction with estimated AR(1) processes for the output gap and government consumption gap in each country, and a simple average among advanced European countries is taken.

Figure 7: Primary Balance to GDP Actuals and Simulations since 2014



(a) US Primary Balance to GDP (b) Europe Primary Balance to GDP

Note: For details on the construction of this simulations see note on figure 6.

We describe below the structure of preferences, technology and the government sector of the home country. The same structure applies to the foreign country, and when needed foreign country variables are identified by an asterisk.

3.1.1 Households, Firms and Government

(a) Households

The preferences of the representative home household are standard:

$$\sum_{t=0}^{\infty} \tilde{\beta}^t \frac{(c_t(1-l_t)^a)^{1-\sigma}}{1-\sigma}, \sigma > 1, a > 0, \text{ and } 0 < \tilde{\beta} < 1. \tag{5}$$

The period utility function is CRRA in terms of a CES composite good made of consumption, c_t, and leisure, $1 - l_t$ (assuming a unit time endowment). $\frac{1}{\sigma}$ is the intertemporal elasticity of substitution in consumption, and a governs both the Frisch and intertemporal elasticities of labor supply for a given value of σ.

The household takes as given proportional tax rates on consumption, labor income and capital income, denoted τ_C, τ_L, and τ_K, respectively, lump-sum government transfers or entitlement payments, denoted by e_t, the rental rates of labor w_t and capital services r_t, and the prices of domestic government bonds and international-traded bonds, q_t^g and q_t.[11]

The household rents $\tilde{k}$ and l to firms, and makes the investment and capacity utilization decisions. As is common in models with endogenous utilization, the rate of depreciation of the capital stock increases with the utilization rate, according to a convex function $\delta(m) = \chi_0 m^{\chi_1}/\chi_1$, with $\chi_1 > 1$ and $\chi_0 > 0$ so that $0 \leq \delta(m) \leq 1$.

Investment incurs quadratic adjustment costs:

$$\phi(k_{t+1}, k_t, m_t) = \frac{\eta}{2}\left(\frac{(1+\gamma)k_{t+1} - (1-\delta(m_t))k_t}{k_t} - z\right)^2 k_t,$$

where the coefficient η determines the speed of adjustment of the capital stock, while z is a constant set equal to the long-run investment-capital ratio, so that at steady state the capital adjustment cost is zero.

The household chooses intertemporal sequences of consumption, leisure, investment inclusive of adjustment costs x, international bonds, domestic government bonds d, and utilization to maximize (5) subject to a sequence of period budget constraints given by:

$$(1+\tau_c)c_t + x_t + (1+\gamma)(q_t b_{t+1} + q_t^g d_{t+1}) = (1-\tau_L)w_t l_t + (1-\tau_K)r_t m_t k_t + \theta\tau_K\bar{\delta}k_t + b_t + d_t + e_t, \quad (6)$$

and the following law of motion for the capital stock:

$$x_t = (1+\gamma)k_{t+1} - (1-\delta(m_t))k_t + \phi(k_{t+1}, k_t, m_t),$$

for $t = 0, ..., \infty$, given the initial conditions $k_0 > 0$, b_0, and d_0.

The left-hand-side of equation (6) includes all the uses of household income, and the right-hand-side includes all the sources net of income taxes and adjustment costs. We impose a standard no-Ponzi-game condition on households, and hence the present value of total household expenditures equals the present value of after-tax income plus initial asset holdings.

Notice that in calculating post-tax income in the above budget constraints, we consider a capital tax allowance $\theta\tau_K\bar{\delta}k_t$ for a fraction θ of depreciation costs. This formulation of the depreciation allowance reflects two assumptions about how the allowance works in actual tax codes: First, depreciation allowances are usually set in terms of fixed depreciation rates of the book or tax value of capital, instead of the true physical depreciation rate that varies with utilization. Hence, we set the depreciation rate for the capital tax allowance at a constant rate $\bar{\delta}$ that differs from the actual physical depreciation rate $\delta(m)$. The second assumption is that the depreciation allowance only applies to a fraction θ of the capital stock, because in practice they generally apply only to the capital income of businesses and self-employed, and do not apply to residential capital.[12]

We assume that capital income is taxed according to the residence principle, in line with features of the tax systems in the United States and Europe, but countries are allowed to tax capital income at different rates. This also implies, however, that in order to support a competitive equilibrium with different capital taxes we must assume that physical capital is owned entirely by domestic residents. (See Mendoza and

[11] The gross yields in these bonds are simply the reciprocal of these prices.

[12] The standard 100-percent depreciation allowance has two unrealistic implications. First, it renders m independent of τ_k in the long run. Second, in the short run τ_k affects the utilization decision margin only to the extent that it reduces the marginal benefit of utilization when traded off against the marginal cost due to changes in the marginal cost of investment.

Tesar (1998).) Without this assumption, cross-country arbitrage of returns across capital and bonds at common world prices implies equalization of pre- and post-tax returns on capital, which therefore requires identical capital income taxes across countries. For the same reason, we must assume that international bond payments are taxed at a common world rate, which we set to zero for simplicity. Other forms of financial-market segmentation, such as trading costs or short-selling constraints, could be introduced for the same purpose, but make the model less tractable.

(b) Firms

Firms hire labor and effective capital services to maximize profits, given by $y_t - w_t l_t - r_t \tilde{k}_t$, taking factor rental rates as given. The production function is assumed to be Cobb-Douglas:

$$y_t = F(\tilde{k}_t, l_t) = \tilde{k}_t^{1-\alpha} l_t^{\alpha}$$

where α is labor's share of income and $0 < \alpha < 1$. Firms behave competitively and thus choose $\tilde{k}_t$ and l_t according to standard conditions:

$$\begin{aligned} (1-\alpha)\tilde{k}_t^{-\alpha} l_t^{\alpha} &= r_t, \\ \alpha \tilde{k}_t l_t^{\alpha-1} &= w_t. \end{aligned}$$

Because of the linear homogeneity of the production technology, these factor demand conditions imply that at equilibrium $y_t = w_t l_t + r_t \tilde{k}_t$.

(c) Government

Fiscal policy has three components. First, government outlays, which include pre-determined sequences of government purchases of goods, g_t, and transfer/entitlement payments, e_t, for $t = 0, ..., \infty$. In our baseline results, we assume that $g_t = \bar{g}$ and $e_t = \bar{e}$ where $\bar{g}$ and $\bar{e}$ are the steady state levels of government purchases and transfers before the post-2008 surge in publice debt. Because entitlements are lump-sum transfer payments, they are always non-distortionary in this representative agent setup, but still a calibrated value of $\bar{e}$ creates the need for the government to raise distortionary tax revenue, since we do not allow for lump-sum taxation.Government purchases do not enter in household utility or the production function, and hence it would follow trivially that a strategy to restore fiscal solvency after an increase in debt should include setting $g_t = 0$. We rule out this possibility because it is unrealistic, and also because if the model is modified to allow government purchases to provide utility or production benefits, cuts in these purchases would be distortionary in a way analogous to taxes. We wil explore this tradeoff in some of the numerical experiments we conduct later.

The second component of fiscal policy is the tax structure. This includes time invariant tax rates on consumption τ_C, labor income τ_L, capital income τ_K, and the depreciation allowance limited to a fraction θ of depreciation expenses.

The third component is government debt, d_t. We assume the government is committed to repay its debt, and thus it must satisfy the following sequence of budget constraints for $t = 0, ..., \infty$:

$$d_t - (1+\gamma) q_t^g d_{t+1} = \tau_C c_t + \tau_L w_t l_t + \tau_K (r_t m_t - \theta \bar{\delta}) k_t - (g_t + e_t).$$

The right-hand-side of this equation is the primary fiscal balance, which is financed with the change in debt net of debt service in the left-hand-side of the constraint.

Public debt is sustainable in this setup in the same sense as we defined it in Section 2. The IGBC must hold (or equivalently, the government must also satisfy a No-Ponzi-game condition): The present value of the primary fiscal balance equals the initial public debt d_0. Since we calibrate the model using shares of GDP, it is useful to re-write the IGBC also in shares of GDP. Defining the primary balance as $pb_t \equiv \tau_C c_t + \tau_L w_t l_t + \tau_K(r_t m_t - \theta\bar{\delta})k_t - (g_t + e_t)$, the IGBC in shares of GDP is:

$$\frac{d_0}{y_{-1}} = \psi_0 \left[\frac{pb_0}{y_0} + \sum_{t=1}^{\infty} \left(\left[\prod_{i=0}^{t-1} \upsilon_i \right] \frac{pb_t}{y_t} \right) \right], \tag{7}$$

where $\upsilon_i \equiv (1+\gamma)\psi_i q_i^g$ and $\psi_i \equiv y_{i+1}/y_i$. In this expression, primary balances are discounted to account for long-run growth at rate γ, transitional growth ψ_i as the economy converges to the long-run, and the equilibrium price of public debt q_i^g. Since y_0 is endogenous (i.e. it responds to increases in d_0 and the fiscal policy adjustments needed to offet them), we write the debt ratio in the left-hand-side as a share of pre-debt-shock output y_{-1}, which is pre-determined.

Combining the budget constraints of the household and the government, and the firm's zero-profit condition, we obtain the home resource constraint:

$$F(m_t k_t, l_t) - c_t - g_t - x_t = (1+\gamma) q_t b_{t+1} - b_t.$$

3.1.2 Equilibrium, Tax Distortions & International Externalities

A competitive equilibrium for the model is a sequence of prices $\{r_t,\ r_t^*,\ q_t,\ q_t^g,\ q_t^{g*},\ w_t,\ w_t^*\}$ and allocations $\{k_{t+1},\ k_{t+1}^*,\ m_{t+1},\ m_{t+1}^*,\ b_{t+1},\ b_{t+1}^*,\ x_t,\ x_t^*,\ l_t,\ l_t^*,\ c_t,\ c_t^*,\ d_{t+1},\ d_{t+1}^*\}$ for $t = 0, ..., \infty$ such that: (a) households in each region maximize utility subject to their corresponding budget constraints and no-Ponzi game constraints, taking as given all fiscal policy variables, pre-tax prices and factor rental rates, (b) firms maximize profits subject to the Cobb-Douglas technology taking as given pre-tax factor rental rates, (c) the government budget constraints hold for given tax rates and exogenous sequences of government purchases and entitlements, and (d) the following market-clearing conditions hold in the global markets of goods and bonds:

$$\omega\left(y_t - c_t - x_t - g_t\right) + (1-\omega)\left(y_t^* - c_t^* - x_t^* - g_t^*\right) = 0,$$
$$\omega b_t + (1-\omega) b_t^* = 0,$$

where ω denotes the initial relative size of the two regions.

The model's optimality conditions are useful for characterizing the model's tax distortions and their international externalities. Consider first the Euler equations for capital (excluding adjustment costs for simplicity), international bonds and domestic government bonds. These equations yield the following arbitrage conditions:

$$\frac{(1+\gamma)u_1(c_t, 1-l_t)}{\tilde{\beta} u_1(c_{t+1}, 1-l_{t+1})} = (1-\tau_K)F_1(m_{t+1}k_{t+1}, l_{t+1})m_{t+1} + 1 - \delta(m_{t+1}) + \tau_K\theta\bar{\delta} = \frac{1}{q_t} = \frac{1}{q_t^g}, \tag{8}$$

$$\frac{(1+\gamma)u_1(c_t^*, 1-l_t^*)}{\tilde{\beta} u_1(c_{t+1}^*, 1-l_{t+1}^*)} = (1-\tau_K^*)F_1(m_{t+1}^*k_{t+1}^*, l_{t+1}^*)m_{t+1}^* + 1 - \delta(m_{t+1}^*) + \tau_K^*\theta\bar{\delta} = \frac{1}{q_t} = \frac{1}{q_t^{g*}}.$$

Fully integrated financial markets imply that intertemporal marginal rates of substitution in consumption are equalized across regions, and are also equal to the rate of return on international bonds. Since physical capital is immobile across countries, and capital income taxes are residence-based, households in each region face their own region's tax on capital income. Arbitrage equalizes the after-tax returns on capital across regions, but pre-tax returns differ, and hence differences in tax rates are reflected in differences in capital stocks and output across regions. Arbitrage in asset markets also implies that bond prices are equalized. Hence, at equilibrium: $q_t = q_t^g = q_t^{g*}$.

As shown in Mendoza and Tesar (1998), unilateral changes in the capital income tax result in a permanent reallocation of physical capital, and ultimately a permanent shift in wealth, from a high-tax to a low-tax region. Thus, even though physical capital is immobile across countries, perfect mobility of financial capital and arbitrage of asset returns induces movements akin to international mobility of physical capital. In the stationary state with balanced growth, however, the global interest rate R (the inverse of the bond price, $R \equiv 1/q$) is a function of β, γ and σ:

$$R = \frac{(1+\gamma)^{\sigma}}{\beta},$$

and thus is independent of tax rates. The interest rate does change along the transition path and alters the paths of consumption, output and international asset holdings. In particular, as is standard in the international tax competition literature, each would have an incentive to behave strategically by tilting the path of the world interest rate in its favor to attract more capital. When both countries attempt this, the outcome is lower capital taxes but also lower welfare for both (which is the well-known race-to-the-bottom result of the tax competition literature).

Consider next the optimality condition:

$$\frac{u_2(c_t, 1-l_t)}{u_1(c_t, 1-l_t)} = \frac{1-\tau_L}{1+\tau_C} F_2(k_t, l_t).$$

Labor and consumption taxes drive the standard wedge $(1-\tau_W) \equiv (1-\tau_L)/(1+\tau_C)$ between the leisure-consumption marginal rate of substitution and the pre-tax real wage (which is equal to the marginal product of labor). Since government outlays are kept constant and the consumption tax is constant, consumption taxation does not distort saving plans, and hence any (τ_C, τ_L) pair consistent with the same τ_W yields identical allocations, prices and welfare.

Many Neoclassical and Keynesian open-economy dynamic equilbrium models feature tax distortions like the ones discussed above, but they also tend to underestimate the elasticity of the capital tax base to changes in capital taxes, because k is pre-determined at the beginning of each period, and changes gradually as it converges to steady state. In the model we described, the elasticity of the capital tax base can be adjusted to match the data because capital income taxes have an additional distortion absent from the other models: They distort capacity utilization decisions. In particular, the optimality condition for the choice of m_t is:

$$F_1(m_t k_t, l_t) = \frac{1+\Phi_t}{1-\tau_K}\delta'(m_t), \tag{9}$$

where $\Phi_t = \eta\left(\frac{(1+\gamma)k_{t+1}-(1-\delta(m_t))k_t}{k_t} - z\right)$ is the marginal adjustment cost of investment. The capital tax creates a wedge between the marginal benefit of utilization on the left-hand-side of this condition and the marginal cost of utilization on the right-hand-side. An increase in τ_k, everything else constant, reduces the utilization rate.[13] Intuitively, a higher capital tax reduces the after-tax marginal benefit of utilization, and thus reduces the rate of utilization. Note also that the magnitude of this distortion depends on where the capital stock is relative to its steady state, because the sign of Φ_t depends on Tobin's Q, which is given by $Q_t = 1 + \Phi_t$. If $Q_t > 1$ ($\Phi_t > 0$), the desired investment rate is higher than the steady-state investment rate. In this case, $Q_t > 1$ increases the marginal cost of utilization (because higher utilization means faster depreciation, which makes it harder to attain the higher target capital stock). The opposite happens if $Q < 1$ ($\Phi_t < 0$). In this case, the faster depreciation at higher utilization rates makes it easier to run down the capital stock to reach its lower target level. Thus, an increase in τ_k induces a larger decline in the utilization rate when the desired investment rate is higher than its long-run target (i.e. $\Phi_t > 0$).

The interaction of endogenous utilization and the limited depreciation allowance plays an important role this setup. Endogenous utilization means that the government cannot treat the existing (pre-determined)

[13] This follows from the concavity of the production function and the fact that $\delta(m_t)$ is increasing and convex.

k as an inelastic source of taxation, because effective capital services decline with the capital tax rate even when the capital stock is already installed. This weakens the revenue-generating capacity of capital taxation, and it also makes capital taxes more distorting, since it gives agents an additional margin of adjustment in response to capital tax hikes (i.e. capital taxes increase the post-tax marginal cost of utilization, as shown in eq. 9). The limited depreciation allowance widens the base of the capital tax, but it also strengthens the distortionary effect of τ_k by reducing the post-tax marginal return on capital (see eq. 8). As we show in the quantitative results, the two mechanisms result in a dynamic Laffer curve with a standard bell shape and consistent with empirical estimates of the capital tax base elasticity, while removing them results in a Laffer curve that is nearly-linearly increasing for a wide range of capital taxes.

The cross-country externalities from tax changes work through three distinct transmission channels that result from the tax distortions we discussed. First, relative prices, because national tax changes alter the prices of financial assets (including internationally traded assets and public debt instruments) as well as the rental prices of effective capital units and labor. Second, the distribution of wealth across the regions, because efficiency effects of tax changes by one region affect the allocations of capital and net foreign assets across regions (even when physical capital is not directly mobile). Third, the erosion of tax revenues, because via the first two channels the tax policies of one region affect the ability of the other region to raise tax revenue. When one region responds to a debt shock by altering its tax rates, it generates external effects on the other region via these three channels.

3.2 Calibration to Europe and the United States

We use data from the United States and the 15 largest European countries to calibrate the model at a quarterly frequency.[14] We calibrate the home region (US) to the United States, and the foreign region (EU15) to the aggregate of the 15 european countries. The EU15 aggregates are GDP-weighted averages. Table 5 presents key macroeconomic statistics and fiscal variables for the all the countries and the two region aggregates in 2008.

The first three rows of Table 5 show estimates of effective tax rates on consumption, labor and capital calculated from revenue and national income accounts statistics using the methodology originally introduced by Mendoza, Razin, and Tesar (1994) (MRT). The US and EU15 have significantly different tax structures. Consumption and labor tax rates are much higher in EU15 than in US (0.17 v. 0.04 for τ_C and 0.41 v. 0.27 for τ_L), while capital taxes are higher in US (0.37 v. 0.32). The labor and consumption tax rates imply a consumption-leisure tax wedge τ_W of 0.298 for the United States v. and 0.496 in EU15. Thus, the EU15 has much higher effective tax distortion on labor supply. Notice also that inside of EU15 there is also some tax heterogeneity, particularly with respect to Great Britain, which has higher capital tax and lower labor tax than most of the other EU15 countries.

With regard to aggregate expenditure-GDP ratios, US has a much higher consumption share than EU15, by 11 percentage points. EU15 has a larger government expenditure share (current purchases of goods and services, excluding transfers) than US by 5 percentage points. Their investment shares are about the same, at 0.21. For net exports, the U.S. has a deficit of 5 percent while EU15 has a balanced trade (with the caveat that the latter includes all trade the individual EU15 countries conduct with each other and with the rest of the world). In light of this, we set the trade balance to zero in both countries for simplicity. In terms of fiscal flows, both total tax revenues and government outlays (including expenditures and transfer payments) as shares of GDP are higher in EU15 than in US, by 13 and 8 percentage points, respectively. Thus, the two

[14] The European countries in our sample include Austria, Belgium, Denmark, Finland, Greece, France, Germany, Ireland, Italy, the Netherlands, Poland, Portugal, Spain, Sweden, and the United Kingdom. These countries account for over 94% of the EU GDP.

regions differ sharply in all three fiscal instruments (taxes, current government expenditures, and transfer payments).

The bottom panel of Table 5 reports government debt to GDP ratios and their change between end–2007 (beginning of 2008) and end–2011. These changes are our estimate of the increases in debt (or "debt shocks") that each country and region experienced, and hence they are the key exogenous impulse used in the quantitative experiments. These debt ratios correspond to general government net financial liabilities as a share of GDP as reported in *Eurostat*. As the table shows, debt ratios between end–2007 and 2011 rose sharply for all countries except Sweden, where the general government actually has a net asset position (i.e. negative net liabilities) that changed very little. The size of the debt shocks differs substantially across the two regions. US entered the Great Recession with a higher government debt to output ratio than EU15 (0.43 v. 0.38) and experienced a larger increase in the debt ratio (0.31 v. 0.20).

Table 6 lists the calibrated parameter values and the main source for each value. The calibration is set so as to represent the balanced-growth steady state that prevailed before the debt shocks occurred using 2008 empirical observations for the corresponding allocations. The value of ω is set at 0.46 so as to match the observation that the United States accounts for about 46 percent of the combined GDP of US and EU15 in 2008. Tax rates, government expenditures share and debt ratios are calibrated to the values in the US and EU15 columns of Table 5 respectively. The limit on the depreciation allowance, θ, is set to capture the facts that tax allowances for depreciation costs apply only to capital income taxation levied on businesses and self-employed, and do not apply to residential capital (which *is* included in k). Hence, the value of θ is set as $\theta = (REV_K^{corp}/REV_K)(K^{NR}/K)$, where (REV_K^{corp}/REV_K) is the ratio of revenue from corporate capital income taxes to total capital income tax revenue, and (K^{NR}/K) is the ratio of non-residential fixed capital to total fixed capital. Using 2007 data from OECD *Revenue Statistics* for revenues, and from the European Union's *EU KLEMS* database for capital stocks for the ten countries with sufficient data coverage,[15] these ratios range from 0.32 to 0.5 for (REV_K^{corp}/REV_K) and from 27 to 52 percent for (K^{NR}/K). Weighting by GDP, the aggregate value of θ is 0.20. Also the value for the U.S. is close to the weighted value for the european countries.

The technology and preferences parameters are set the same across the U.S. and the EU15, except the parameters χ_0 and χ_1 in the depreciation function. The common parameters are calibrated to target the weighted average statistics for all sample countries. The labor share of income, α, is set to 0.61, following Trabandt and Uhlig (2011). The quarterly rate of labor-augmenting technological change, γ, is 0.0038, which corresponds to the 1.51 percent weighted average annual growth rate in real GDP per capita of all the countries in our sample between 1995 and 2011, based on Eurostat data. We normalize the long-run capacity utilization rate to $\bar{m} = 1$. Given γ at 0.0038, x/y at 0.19 and k/y at 2.62 from the data, we solve for the long-run depreciation rate from the steady-state law of motion of the capital stock, $x/y = (\gamma + \delta(\bar{m}))k/y$.[16] This yields $\delta(\bar{m}) = 0.0163$ per quarter. The constant depreciation rate for claiming the depreciation tax allowance, $\bar{\delta}$, is set equal to the steady state depreciation rate of 0.0163.

The value of χ_0 follows then from the optimality condition for utilization at steady state, which yields $\chi_0 = \delta(\bar{m}) + \frac{1+\gamma-\beta}{\beta} - \tau_K\bar{\delta}$. Given this, the value of χ_1 follows from evaluating the depreciation rate function at steady state, which implies $\chi_0\bar{m}^{\chi_1}/\chi_1 = \delta(\bar{m})$. Given the different capital tax rates in the U.S. and the EU15, the implied values for χ_0 and χ_1 are slightly different across countries: χ_0 is 0.0233 in US and 0.0235 in the EU15, and χ_1 is 1.435 in US and 1.445 in the EU15.

The preference parameter, σ, is set at a commonly used value of 2. The exponent of leisure in utility is set at $a = 2.675$, which is taken from Mendoza and Tesar (1998). This value supports a labor allocation of

[15] These countries are Austria, Denmark, Finland, Germany, Italy, Netherlands, Spain, Sweden, the United Kingdom, and the United States.

[16] Investment rates are from the OECD National Income Accounts and capital-output ratios are from the AMECO database of the European Commission.

18.2 hours, which is in the range of the 1993-1996 averages of hours worked per person aged 15 to 64 reported by Prescott (2004). The value of β follows from the steady-state Euler equation for capital accumulation, using the values set above for the other parameters that appear in this equation:

$$\frac{\gamma}{\tilde{\beta}} = 1 + (1 - \tau_K)(1 - \alpha)\frac{y}{k} - \delta(\bar{m}) + \tau_K \theta \bar{\delta}.$$

This yields $\tilde{\beta} = 0.995$, and then since $\tilde{\beta} = \beta(1+\gamma)^{1-\sigma}$ it follows that $\beta = 0.998$. The values of β, γ and σ pin down the steady-state gross real interest rate, $R = \beta^{-1}(1+\gamma)^{\sigma} = 1.0093$. This is equivalent to a net annual real interest rate of about 3.8 percent.

Once R is determined, the steady-state ratio of net foreign assets to GDP is pinned down by the net exports-GDP ratio. Since we set $tb/y = 0$, $b/y = (tb/y)/\left[(1+\gamma)R^{-1} - 1\right] = 0$. In addition, the steady-state government budget constraint yields an implied ratio of government entitlement payments to GDP $e/y = Rev/y - g/y - (d/y)\left[1 - (1+\gamma)R^{-1}\right] = 0.196$. Under this calibration approach, both b/y and e/y are obtained as residuals, given that the values of all the terms in the right-hand-side of the equations that determine them have already been set. Hence, they generally will not match their empirical counterparts. In particular, for entitlement payments the model underestimates the 2008 observed ratio of entitlement payments to GDP (0.196 in the model v. 0.26 in the data for All EU). Notice, however, that when the model is used to evaluate tax policies to restore fiscal solvency, the fact that entitlement payments are lower than in the data strengthens our results, because lower entitlements means that a lower required amount of revenue than what would be needed to support observed transfer payments, thus making it easier to restore solvency. We show below that restoring fiscal solvency is difficult and implies non-trivial tax adjustments with sizable welfare costs and cross-country spillovers, all of which would be larger with higher government revenue requirements due to higher entitlement payments.

The value of the investment-adjustment-cost parameter, η, cannot be set using steady-state conditions, because adjustment costs wash out at steady state. Hence, we set the value of η so that the model is consistent with the mid-point of the empirical estimates of the short-run elasticity of the capital tax base to changes in capital tax rates. The range of empirical estimates is 0.1–0.5, so the target midpoint is 0.3.[17] Under the baseline symmetric calibration, the model matches this short-run elasticity with $\eta = 2.0$. This is also in line with estimates in House and Shapiro (2008) of the response of investment in long-lived capital goods to relatively temporary changes in the cost of capital goods.[18]

Table 7 reports the 2008 GDP ratios of key macro-aggregates in the data and the model's steady-state allocations for the US-EU15 calibration. As noted earlier, this calibration captures the observed differences in the size of the regions, their fiscal policy parameters, and their public debt-GDP ratios. Notice in particular that the consumption-output ratios and the fiscal revenue-output ratios from the data were not directly targeted in the calibration, but the two are closely matched by the model. Hence, the model's initial stationary equilibrium before the increases in public debt is a reasonably good match to the observed initial conditions in the data.

[17] The main estimate of the elasticity of the *corporate* tax base relative to corporate taxes in the United States obtained by Gruber and Rauh (2007) is 0.2. Dwenger and Steiner (2012) obtained around 0.5 for Germany. Grubler and Rauh also reviewed the large literature estimating the elasticity of *individual* tax bases to individual tax rates and noted this: "The broad consensus...is that the elasticity of taxable income with respect to the tax rate is roughly 0.4. Moreover, the elasticity of actual income generation through labor supply/savings, as opposed to reported income, is much lower. And most of the response of taxable income to taxation appears to arise from higher income groups."

[18] They estimated an elasticity of substitution between capital and consumption goods in the 6-14 range. In the variant of our model without utilization choice, this elasticity is equal to $1/(\eta\delta)$. Hence, for $\delta(\bar{m}) = 0.0164$, elasticities in that range imply values of η in the 1-2.5 range.

3.3 Quantitative Results

The goal of the quantitative experiments is to use the numerical solutions of the model to study whether alternative fiscal policies can restore fiscal solvency, which requires increasing the present discounted value of the primary balance in the right-hand-side of (7) by as much as the observed increases in debt.[19] Notice that the change in this present value reflects changes in the endogenous equilibrium dynamics of the primary balance-GDP ratio in response to the changes in fiscal policy variables. In turn, the changes in primary balance dynamics reflect the effects of these policy changes on equilibrium allocations and prices that determine tax bases, and the computation of the present value reflects also the response of the equilibrium interest rates (i.e. debt prices).

We conduct a set of experiments in which we assume that US or EU15 implement unilateral increases in either capital or labor tax rates, so we can quantify the effects on equilibrium allocations and prices, sustainable debt (i.e. primary balance dynamics), and social welfare in both regions. We also compare these results with those obtained if the same tax changes are implemented assuming the countries are closed economies, so we can highlight the cross-country externalities of unilateral tax changes.

The model is solved numerically using a modified version of the algorithm developed by Mendoza and Tesar (1998, 2005), which is based on a first-order approximation to the equilibrium conditions around the steady state. Since models of this class consist of two fully integrated regions, standard perturbation methods cannot be applied directly. In particular, trade in bonds implies that, when the model's pre-debt-crisis steady state is perturbed, the equilibrium transition paths of allocations and prices and the new steady-state equilibrium need to be solved for simultaneously. This is because in models of this class stationary equilibria depend on initial conditions, and thus cannot be determined separately from the models' dynamics. Mendoza and Tesar dealt with this problem by developing a solution method that nests a perturbation routine for solving transitional dynamics within a shooting algorithm. This method iterates on candidate values of the new long-run net foreign asset positions to which the model converges after being perturbed by debt and tax changes, until the candidate values match the positions the model converges to when simulated forward to its new steady state starting from the calibrated pre-debt-crisis initial conditions.

3.3.1 Dynamic Laffer Curves

We start by constructing "Dynamic Laffer Curves" (DLC) that show how unilateral changes in capital or labor taxes in one region affect that region's sustainable public debt. These curves map values of τ_K or τ_L into the equilibrium present discounted value of the primary fiscal balance. For each value that the tax rate in the horizontal axis takes, we solve the model to compute the intertemporal sequence of total tax revenue, which varies as equilibrium allocations and prices vary, while government purchases and entitlement payments are kept constant. Then we compute the present value of the primary balance, which therefore captures the effect of changes in the equilibrium sequence of interest rates. We take the ratio of this present value to the initial output y_{-1} (i.e. GDP in the steady state calibrated to pre-2008 data) so that it corresponds to the term in the right-hand-side of the IGBC (7), and plot the result as a *change* relative to the 2007 public debt ratio. Hence, the values along the vertical axis of the DLCs show the change in d_0/y_{-1} that particular values of τ_K or τ_L can support as sustainable debt at equilibrium (i.e. debt that satisfies the IGBC with equality). By construction, the curves cross the zero line at the calibrated tax rates of the initial stationary equilibrium, because those tax rates yield exactly the same present discounted value of the primary balance as the initial calibration. To make the observed debt increases sustainable, there needs to be a value of the

[19] The observed increases in debt between end–2007 (beginning of 2008) and end–2011 can be viewed as exogenous increases in d_0/y_{-1} in the left-hand-side of the IGBC (7). As reported in Table 5, the U.S. debt ratio rose by 31 percentange points from 41 percent, and that of the EU15 rose by 20 percentage points from 38 percent.

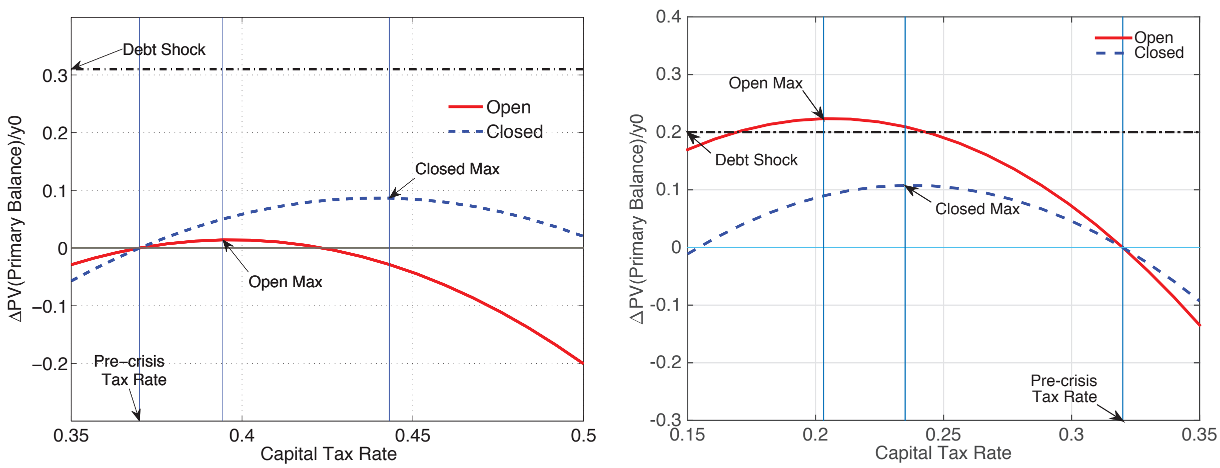
tax rate in the horizontal axis such that the DLC returns a value in the vertical axis that matches the change in debt.

Since the "passive" region whose taxes are not being changed unilaterally is affected by spillovers of the other region's tax changes, there needs be an adjustment in the passive region so that its IGBC is unchanged (i.e. it maintains the same present discounted value of primary fiscal balances). We refer to this adjustment as maintaining "revenue neutrality" in the passive region. In principle this can be done by changing transfers, taxes or government purchases. However, since we have assumed already that government purchases are kept constant in both regions, reducing distortionary tax rates in response to favorable tax spillovers would be more desirable than increasing transfer payments, which are non-distortionary. Hence, we maintain revenue neutrality in the passive region by adjusting the labor tax rate.

Dynamic Laffer Curves for Capital Taxes

The DLCs for capital taxes are plotted in Figure 8. The left panel is for the US region, and the right panel is for EU15. The solid lines show the open- economy curves and the dotted lines are for when the countries are in autarky. As explained above, the DLCs intersect the zero line at the initial tax rates of $\tau_K = 0.37$ and $\tau_K^* = 0.32$ by construction. We also show in the plots the increases in debt observed in each region, as shown in Table 5: The US net public debt ratio rose 31 percentage points and that of the EU15 rose 20 percentage points. These increases are marked with the "Debt Shock" line in Figure 8.

Figure 8: Dynamic Laffer Curves of Capital Tax Rates



(a) US

(b) EU15

Figure 8 shows that the DLCs of US and EU15 are very different, with those for EU15 seating higher, shifted to the left, and showing more curvature than those for US. Hence, unilateral changes in capital tax rates show a capacity to sustain larger debt increases in EU15 than in US, and can do so at lower tax rates. These marked differences are the result of the heterogeneity in fiscal policies present in the data and captured in the calibration, and in the open-economy scenario they are also partly explained by the international externalities of unilateral tax changes. EU15 has higher revenue-generating capacity because of higher labor and consumption taxes at identical labor income shares and similar consumption shares, although in terms of primary balance the higher revenue is partly offset by higher government purchases. On the other hand, US has a lower capital tax rate and by enough to make a significant difference in the inefficiencies created by capital taxes across the two regions, as we illustarte in more detail below. Moreover, the magnitude of heterogeneity in the capital tax DLCs that results from a given magnitude of heterogeneity in fiscal variables depends on the model's modifications made to match the observed elasticity of the capital base. We illustrate below that DLCs are very different if we remove capacity utilization and the limited depreciation allowance.

Beyond the difference in position and shape of the capital tax DLCs across US and EU15, these DLCs deliver three striking results: First, unilateral changes in the US capital tax cannot restore fiscal solvency and make the observed increase in debt sustainable (the peaks of the DLCs of the US region either as a closed or an open economy are significantly below the debt shock line). The maximum point of the open-economy DLC is attained around τ_K =0.4, which produces an increase in the present value of the primary balance of only 2 percentage points of GDP, far short of the required 31. In contrast, , the maximum point of the open-economy DLC for EU15 is attained around τ_{K^*} =0.21, which rises the present value of the primary balance by 22 percentage points of GDP, slightly more than the required 20. Under autarky, however, the EU15 DLC also peaks below the required level, and hence capital taxes also cannot restore fiscal solvency for EU15 as a closed economy. This result also reflects the strong cross-country externalities that we discuss in more detail below (i.e. unilateral capital tax reductions yield significantly more sustainable debt for EU15 as an open economy than under autarky).

Second, capital income taxes in EU15 are highly inefficient. The current capital tax rate is on the increasing segment of the DLC for US but on the decreasing segment for EU15. This has two important implications. One is that EU15 could have sustained the calibrated initial debt ratio of 38 percent at capital taxes below 15 percent, instead of the 32 percent tax rate obtained from the data. The second is that to make the observed 20 percentage points increase in debt sustainable, EU15 can *reduce* its capital tax almost in half to about 17 percent in the open-economy DLC. In both cases, the sharply lower capital taxes would be much less distortionary and thus would increase efficiency significantly.

Third, cross-country externalities of capital income taxes are very strong, and under our baseline calibration, they hurt (favor) the capacity to sustain debt of US (EU15). For US, the DLC under autarky is steeper than in the open-economy case, and it peaks at a higher tax rate of 43 percent and with a higher increase in the present value of the primary balance of about 10 percentage points. Thus, US can always sustain more debt, or support higher debt increases relative to the calibrated baseline, for a given increase in τ_K under autarky than as an open economy. This occurs because by increasing its capital tax *unilaterally* as an open economy the US not only suffers the efficiency losses in capital accumulation and utilization, but it also triggers reallocation of physical capital from US to EU15, which results in reductions (increases) in US (EU15) factor payments and consumption, and thus lower (higher) tax bases in US (EU15). The same mechanism explains why reducing the capital tax in the EU15 unilaterally generates much less revenue under autarky than in the open-economy case. In the latter, cutting the EU15 capital tax unilaterally triggers the same forces as a unilateral increase in the US capital tax.

This quantitative evidence of strong externalities of capital taxes across financially integrated economies demonstrates that evaluating "fiscal space," or the capacity to sustain debt, using closed-economy models leads to seriously flawed estimates of the effectiveness of capital taxes as a tool to restore debt sustainability. The results also suggest that incentives for strategic interaction leading to capital income tax competition are strong, and get stronger as higher debts need to be reconciled with fiscal solvency (as evidenced by the experience inside the EU since the 1980s). Mendoza, Tesar, and Zhang (2014) study this issue using a calibration that splits the European Union into two regions, one including the countries most affected by the European debt crisis (Greece, Ireland, Italy, Portugal and Spain) and the second including the rest of the Eurozone members.

Dynamic Laffer Curves of Labor Tax Rates

Figure 9 shows the DLCs for the labor tax rate. Notice that the open-economy and autarky DLCs are similar (although more similar for EU15 than for US), which indicates that international externalities are much weaker in this case. This is natural, because labor is an immobile factor, and altough it can still trigger cross-country spillovers via general-equilibrium mechanisms, these are much weaker than the first-order effects created by unilateral changes of capital taxes via the condition that arbitrages after-tax returns on all assets across countries.

The main result of the DLCs for labor taxes, is that the DLCs for US are much higher than those for the EU15. Since the international externalities are weak for the labor tax, this result is only due to the different initial conditions resulting from the fiscal heterogeneity captured in our calibration, and in particular to the large difference in initial labor taxes (41 v. 27 percent in the EU15 v. US respectively). Increasing the calibrated τ_L for the US region to the EU15 rate of 41 percent, keeping all other US parameters unchanged, shifts down its labor tax DLC almost uniformly by about 200 percentage points in the 0.25-0.55 interval of labor tax rates. This happens because, for an increase in the labor tax of a given size, the difference in initial conditions implies that the US region generates a larger increase in the present value of total tax revenue than EU15, and since the present value of government outlays is nearly unchanged in both, the larger present value of revenue is amplified into a significantly larger increase in the present value of the primary balance.[20]

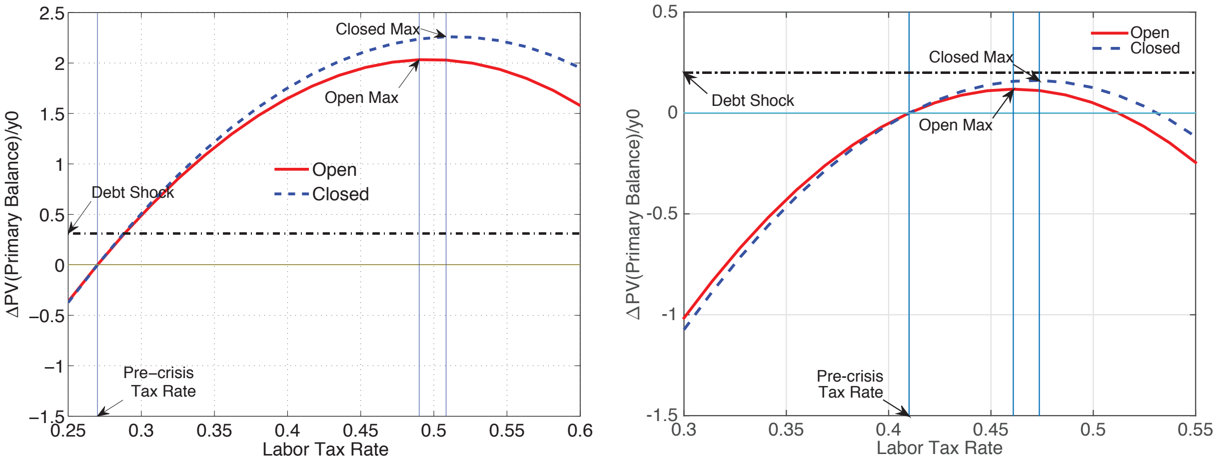
The US open-economy DLC for τ_L is considerably steeper than for τ_K, and it peaks at a tax rate of 0.48, which would make sustainable an initial debt ratio larger than in the initial baseline by 200 percentage points of GDP, much more than the 31 percentage points required by the data. The labor tax rate that US as an open or closed economy needs to make the observed debt increase sustainable is about 29 percent, which is just a two-percentage-point increase relative to the initial tax rate. Hence, these results show that, from the perspective of macroeconomic efficiency that representative-agent models of the class we are using emphasize, labor taxes are a significantly more effective tool for restoring fiscal solvency in the United States than capital taxes.

The DLC of the EU15 yields much less positive results. Since the initial consumption-labor wedge is already much higher in this region than in US, the fiscal space of the labor tax rate is very limited. In either the closed- or open-economy cases, the DLC peaks at a labor tax rate of 46 percent and yields an increase of only about 10 percentage points in the present value of the primary balance, which is half of the 20-percentage-points increase EU15 needs make the observed debt increase sustainable.

It is interesting to note that the debt increase in the United States was about 10 percentage points larger than in Europe, yet the model predicts that given the initial conditions in tax rates and government outlays before the increases in debt, unilateral tax adjustments in Europe cannot generate a sufficient increase in the present value of the primary balance to make their higher debt sustainable. The exception is the capital tax in the open-economy scenario, in which this is possible because of EU15 would benefit significantly from a negative externality on the US region. In contrast, the results show that a modest increase in labor taxes (or consumption taxes since they are equivalent in this model) can restore fiscal solvency in the United States.

[20] The percent change in the present value of the primary balance after a tax change of a given magnitude relative to before (assuming that the present value of government outlays does not change) can be expressed as $z[1 + PDV(g+e)/PDV(pb)]$, where z is the percent change in the present value of tax revenues after the tax change relative to before, and $PDV(g+e)$ and $PDV(pb)$ are the pre-tax-change present values of total government outlays and the primary balance respectively. Hence, for $z > 0$ and since total outlays are much larger than the primary balance $[PDV(g+e)/PDV(pb)] >> 1$, a given difference in z across US and EU15 translates into a much larger percent difference in the present value of the primary balance.

Figure 9: Dynamic Laffer Curves of Labor Tax Rates



(a) US

(b) EU15

3.3.2 Macroeconomic Effects Tax Rate Changes

We analyze next the macroeconomic effects of unilateral changes in capital and labor tax rates. In the first experiment, US increases its capital tax rate from the initial value of 0.37 to 0.402, which is the maximum point of the open-economy DLC for US. Table 8 shows the effects of this change on both regions in the open-economy model and on the US region as a closed economy. The EU15 reduces its labor tax rate from 0.41 to 0.40 to maintain revenue neutrality, which is the result of favorable externalities from the tax hike in US.

The capital tax hike in US as an open economy leads to an overall welfare cost of 2.19 percent v. 2.22 percent as a closed economy, while EU15 obtains a welfare gain of 0.74 percent.[21] Comparing the US outcomes as an open economy relative to the closed economy under the same 40.2 percent capital tax rate, we find that the sustainable debt (i.e. the present value of the primary balance) rises by a factor of 4.5 (from 1.37 to 6.16 percent). The welfare loss is nearly the same (2.2 percent), but normalizing by the amount of revenue generated, the US is much better off in autarky. Thus, seen from this perspective, US would have strong incentives for considering measures to limit international capital mobility.

The 0.74 percent welfare gain that EU15 obtains from the US unilateral capital tax hike is a measure of the normative effect of the cross-country externalities of capital tax changes. US can raise more revenue by increasing τ_K along the upward-sloping region of its DLC, but its ability to do so is significantly hampered by the adverse externality it faces due to the erosion of its tax bases. In the EU15, the same externality indirectly improves government finances, or reduces the distortions associated with tax collection, and provides it with an unintended welfare gain.

The impact and long-run effects on key macro-aggregates in both regions are shown in the bottom half of Table 8. The corresponding transition paths as the economies move from the pre-crisis steady state to

[21] Welfare effects are computed as in Lucas (1987), in terms of a percent change in consumption constant across all periods that equates lifetime utility under a given tax rate change with that attained in the initial steady state. The overall effect includes transitional dynamics across the pre- and post-tax-change steady states, as well as changes across steady states. The steady-state effect only includes the latter.

the new steady state are illustrated in Figure A.1 in the appendix. The increase in τ_K causes US capital to fall over time to a level 7.6 percent below the pre-crisis level, while EU15's capital rises to a level 1.2 percent above the pre-tax-change level. Capacity utilization falls at home in both the short run and the long run, which is a key component of the model capturing the reduced revenue-generating capacity of capital tax hikes when the endogeneity of capacity utilization is considered. We show later in this section that this mechanism indeed drives the elasticity of the capital tax base in the model, which matches that of the data and is higher than what standard representative-agent models of taxation show.

On impact when US increases its capital tax, labor increases in US and falls in EU15, but this pattern reverses during the transition to steady state because of the lower (higher) capital stock in US (EU15) region in the new steady state. Consequently, US output contracts by almost 4 percent in the long-run, underscoring efficiency losses due to the capital tax increase and the costs of the fiscal adjustment. US increases its net foreign asset position (NFA) by running trade surpluses (tb/y) in the early stages of transition, while EU15 decreases its NFA position by running trade deficits. The US tarde surpluses reflect saving to smooth out the cost of the efficiency losses, as output follows a monotonically decreasing path. Still, utility levels are lower than when US implements the same capital tax under autarky, because of the negative cross-country spillovers.

The next experiment examines the effects of lowering the EU15 capital tax rate so as to move it out of the decreasing segment of the DLC. To make this change analagous to the one in the previous experiment, we change the EU15 capital tax to the value at the maximum point of the DLC for EU15, which is about 21 percent. Table 9 summarizes the results. The cut in the EU15 capital tax rate generates an increase of about 22 percentage points in sustainable debt (just a notch above what is required to make the observed debt increase sustainable), and a large welfare gain of 6.5 percent for this region. Its capital stock rises over time to a level 25 percent higher than in the pre-tax-change steady state. Output, consumption, labor supply, and utilization all rise in both the short-run and the long-run in EU15, while the trade balance moves initially into a large trade deficit and then converges to a small surplus. The same tax cut in the EU15 as a closed economy yields a much smaller rise in sustainable debt, of just under 10 percentage points, though the welfare gain is about the same as in the open economy. This result indicates that in this case the welfare gain largely reflects the reduction of the large inefficiencies due to the initial capital tax being in the decreasing side of the DLC. Given the weak cross-country externalities of labor taxes, in the US region the tax cut in EU15 causes a welfare loss of 0.2 percent, with capital declining 1.4 percent from the pre-tax-change level.

The next two experiments focus on changes in labor tax rates. The DLCs for the labor tax rate (Figure 9) show that the US region has substantial capacity to raise tax revenues and sustain higher debt ratios by raising labor taxes. We examine in particular an increase of the tax the rate that completely offsets the observed debt increase, which as we noted earlier is only about 2 percentage points higher than in the initial calibration (i.e. the labor tax in US rises from 27 to 29 percent). The results are reported in Table 10. The declines in US output, consumption, capital and welfare are much smaller than with the capital tax hike. Since the international spillovers are small, this tax change produces a welfare gain of just 0.18 percent in the EU15. For the same reason, comparing US results as as a closed v. open economy, the change in the present value of the primary balance is almost the same, in contrast with the large difference obtained for the capital tax. Also, keep in mind that the capital tax hike, even tough it was set at the maximum point of the capital tax DLC of US as open economy, cannot generate enough revenue to offset the observed debt increase, whereas the labor tax hike does.

Now consider the case of increasing the EU15 labor tax. As explained earlier in discussing the labor DLCs, the EU15 initial consumption/labor wedge is already high, so the capacity for raising tax revenues using labor taxes is limited. In this experiment, we increase the labor tax in EU15 to the rate at the maximum point of the labor tax DLC of EU15 as an open economy, which implies a labor tax rate of 0.465. The results are summarized in Table 11. The higher EU15 labor tax increases the present value of the primary balance-GDP ratio by only 0.118, falling well short of the observed debt increase of 0.2. The welfare loss is large, at nearly 5 percent, with output, consumption, capital and labor falling. The EU15 can produce a higher present value of the primary balance (by 0.16) in the closed economy at a similar welfare loss. Again the international spillover for the labor tax rate is small, so the US region makes a negligible welfare gain.

Taken together these findings are consistent with two familiar results from tax analysis in representative-agent models, which emphasize the efficiency costs of tax distortions. First, the capital tax rate is the most distorting tax. Second, in open-economy models, taxation of a mobile factor (i.e. capital) yields less revenue at greater welfare loss than taxation of the immobile factor (i.e. labor). This is in line with our results showing that the cross-country tax externalities are strong for capital taxes but weak for labor taxes.

The sharp differences we found between US and EU15 also have important policy implications in terms of debates about debt-sustainability and the effects of fiscal adjustment via capital and labor taxes in Europe and the United States. With capital taxes, the model suggests that the United States is on the increasing side of the Laffer curve, though it cannot restore fiscal solvency for the observed debt shock of 31 percentage points (neither as an open economy nor as a closed economy). In contrast, the model suggests that Europe is on the decreasing side of the Laffer curve, and can make its observed debt increase of 20 percentage point sustainable by reducing its capital taxes and moving away from the decreasing side of the Laffer curve, and in the process make a substantial welfare gain. With labor taxes, although the model indicates that both the U.S. and Europe are on the increasing side of their DLCs, the U.S. pre-2008 started with a much smaller consumption/labor distortion than Europe, and as a result, the U.S. has substantial fiscal space to easily offset the debt increase with a small tax hike and a small welfare cost of 0.9 percent. In contrast, the model suggests that Europe cannot restore fiscal solvency after the observed increase in debt using labor taxes.

3.3.3 The Importance of Endogenous Utilization and Limited Depreciation Allowance

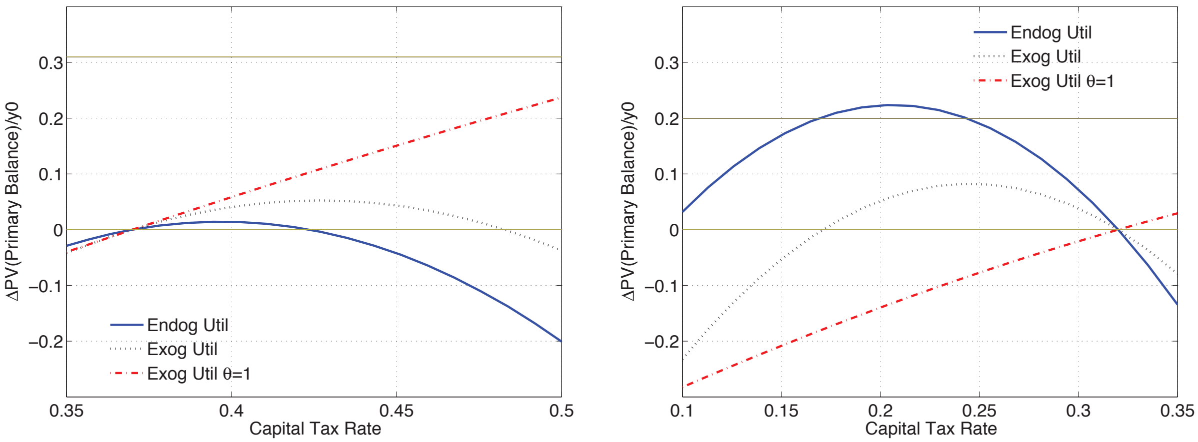
As explained earlier, we borrowed from Mendoza, Tesar, and Zhang (2014) the idea of using endogenous capacity utilization and a limited tax allowance for depreciation expenses to build into the model a mechanism that produces capital tax base elasticities in line with empirical estimates. In contrast, standard dynamic equilibrium models without these features tend to have unrealistically low responses of the capital base to increases in capital taxes. To illustrate this point, we follow again Mendoza et al. in comparing DLCs for capital taxes in three scenarios (see Figure 10): (i) a standard neoclassical model with exogenous utilization and a full depreciation allowance ($\theta = 1$) shown as a dashed-dotted line; (ii) the same model but with a limited depreciation allowance ($\theta = 0.2$) shown as a dotted line; and (iii) the baseline calibration of our model with both endogenous utilization and a limited depreciation allowance (using again $\theta = 0.2$) shown as a solid line. All other parameter values are kept the same. We show the three cases for the US and EU15 region in panels (a) and (b) of the Figure respectively.

The DLCs for the three cases intersect at the initial calibrated tax rates of 0.37 and 0.32 for the US and EU15 by construction. To the right of this point, the curves for case (i) are always above the other two, and the ones for case (ii) are always above the ones for case (iii). The opposite occurs to the left of the intersection points.

Consider the US plots. In case (i), the DLC has a positive, approximately linear slope in the 0.35–0.5 domain of capital tax rates. This curve continues to be increasing even when we extend the capital tax rate to 0.9, which is in line with the results obtained by Trabandt and Uhlig (2011).[22] This behavior of the DLC for the capital tax follows from the fact that at any given date the capital stock is predetermined and has a low short-run elasticity. As a result, the government can raise substantial revenue over the transition period

[22] They find that present-value Laffer curves of capital tax revenue peak at very high tax rates (discounting with the constant steady state interest rate) or have a positive slope over the full range (discounting with equilibrium interest rates).

Figure 10: Comparing Dynamic Laffer Curves for the Capital Tax Rate



(a) US

(b) EU15

because the capital stock declines only gradually. The increased tax revenue during the transition dominates the fall in the steady-state, resulting in a non-decreasing DLC (recall the DLC is based on present value calculations).

Introducing limited depreciation allowance without endogenizing the utilization choice (case (ii)) has two effects that induce concavity in the DLC. First, it increases the effective rate of taxation on capital income, and thus weakens the incentive to accumulate capital and lowers the steady-state capital-output ratio and tax bases. On the other hand, it has a positive impact on revenue by widening the capital tax base. The first effect dominates the latter when the capital tax rate rises relative to the initial tax of 0.37, resulting in sharply lower DLC curve values than in case (i).

In case (iii) the tax allowance is again limited but now capacity utilization is endogenous. This introduces additional effects that operate via the distortions on efficiency and the ability to raise revenue discussed earlier: On the side of tax distortions, equation (9) implies that endogenous utilization adds to the efficiency costs of capital income taxation by introducing a wedge between the marginal cost and benefits of capital utilization. On the revenue side, endogenous utilization allows agents to make adjustments in effective capital (reducing it when taxes rise and increasing it when it falls), and thus alters the level of taxable capital income. Hence, when utilization falls in response to increases in capital tax rates, it also weakens the government's ability to raise capital tax revenue. These effects lead to a bell-shaped DLC that has more curvature and is significantly below those in cases (i) and (ii). Thus, endogenous utilization makes capital taxes more distorting and weakens significantly the revenue-generating capacity of capital taxes.[23]

Panel (b) of Figure 10 shows DLCs for the three cases in the EU15 region. The results are analogous to Panel (a) but emphasizing now the region to the left of the intersection point, which is at the initial tax of 32 percent. In case (i), again the DLC has an increasing positive slope over a large range of the capital tax rate. Case (ii) shows that limiting the depreciation allowance again induces concavity in the DLC, with the EU15 initial capital tax already in the decreasing segment of the curve. Comparing with case (iii), the exogenous utilization case generates much less revenue. As in the US results, this occurs because with endogenous utilization, reductions in capital taxes lead to higher utilization rates that result in higher levels of capital

[23] Mendoza et al. also found that removing the limited depreciation allowance from case (iii) still results in a DLC below those of cases (i) and (ii), but it is also flatter and increasing for a wider range of capital taxes than case (iii).

income and higher wages, thus widening the two income tax bases.

The effects of endogenous utilization and limited depreciation have significant implications for the elasticity of the capital income tax base with respect to the capital tax. In particular, as Mendoza, Tesar and Zhang (2014) showed, the model can be calibrated to match a short-run elasticity consistent with empirical estimates because of the combined effects of those two features. As documented earlier, the empirical literature finds estimates of the short-run elasticity of the capital tax base in the 0.1–0.5 range. Table 12 reports the model's comparable elasticity estimates and the effects on output, labor and utilization one year after a 1-percent increase in the capital tax (relative to the calibrated baseline values), again for cases (i), (ii) and (iii) and in both US and EU15 regions.

The US and EU15 results differ somewhat quantitatively, but qualitatively they make identical points: The neoclassical model with or without limited depreciation allowance (cases (i) and (ii)) yields short-run elasticities with the wrong sign (i.e. the capital tax base *rises* in the short run in response to capital tax rate increases). The reason is that capital income does not change much, since capital is pre-determined in the period of the tax hike and changes little in the first period after because of investment adjustment costs, and labor supply rises due to a negative income shock from the tax hike. Since capital does not fall much and labor rises, output rises on impact, and thus taxable labor and capital income both rise, producing an elasticity of the opposite sign than that found in the data. In contrast, the model with endogenous utilization (case (iii)), generates a decline in output on impact due to a substantial drop in the utilization rate, despite the rise in labor supply. With the calibrated values of η, the model generates short-run elasticities of 0.29 and 0.32 for US and EU15 respectivelye, which are both well inside the range of empirical estimates.

It is also worth noting that with exogenous utilization, the model can produce a capital tax base elasticity in line with empirical evidence only if we set η to an unrealistically low value. The short-run elasticity of the capital tax base is negative for any $\eta > 1$, and it becomes positive and higher than 0.1 only for $\eta < 0.1$.[24] This is significantly below the empirically relevant range of 1–2.5 documented in the calibration section. Moreover, at the value of $\eta = 2$ determined in our baseline calibration, the model without utilization choice yields a capital tax base elasticity of -0.09.

To summarize where the Chapter is at this point, we first explored the question of public debt sustainability from the viewpoint of an empirical approach based on the estimation and analysis of fiscal reaction function. We found that the sufficiency codition for public debt to be sustainable (i.e. for IGBC to hold), reflected in a positive conditional response of the primary balance to public debt, cannot be rejected by the data. At the same time, however, there is clear evidence that the fiscal dynamics observed in the aftermath of the recent surge in debt in advanced economies represent a significant structural break in the reaction functions. In plain terms, primary deficits have been too large, and are projected to remain too large, to be in line with the path projected by the reaction functions, and also relative to the fiscal adjustment process observed in previous episodes of large surges in debt.

The main limitation of the empirical approach is that it cannot say much about the macroeconomic effects of multiple fiscal adjustment paths that can restore debt sustainability. To address this issue, this Section explored a structural approach that takes a variation of the workhorse two-country Neoclassical dynamic equilibrium model with an explicit fiscal sector. Capacity utilization and a limited tax allowance for depreciation expenses were used to match the observed elasticity of the capital tax base to capital tax changes. Then we calibrated this model to U.S. and European data and used it to quantify the effects of unilateral changes in capital and labor taxes aimed at altering the ability of countries to sustain debt. The results suggest striking differences across Europe and the United States. For the United States, the results suggest that changes in capital taxes cannot make the observed increase in debt sustainable, while

[24] The intuition is simple. As η approaches zero the marginal adjustment cost of investment approaches zero, and hence the capital stock one year after the tax hike can respond with large declines.

small increases in labor taxes could. For Europe, the model predicts that the ability of the tax system to make higher debt ratios sustainable is nearly fully exhausted. Capital taxation is highly inefficient and in the decreasing segment of dynamic Laffer curves, so cuts in capital taxes would be needed to restore fiscal solvency. Labor taxes are near the peak of the dynamic Laffer curve, and even if increased to the maximum point they fail to increase the present value of the primary balance to make the observed surge in debt sustainable. Moreover, international externalities of capital income taxes are quantitatively large, suggesting that incentives for strategic interaction, and the classic race-to-the-bottom in capital income taxation are non-trivial.

In short, the results from the empirical and the structural approaches to evaluate debt sustainability cast doubt on the presumption that the high debt ratios reached by many advanced economies in the years since 2008 will be fully repaid. To examine debt sustainability allowing for the possibility of non-repayment, however, we must consider a third approach, because commitment to repay is a central assumption of the two approaches we have covered. In the last Section of this Chapter we turn our attention to this issue.

4 Domestic Default Approach

This Section of the Chapter examines debt sustainability from the perspective of a framework that abandons the assumption of a government committed to repay its domestic debt. The emphasis is on the risk of de-jure, or outright, default on domestic public debt, not the far more studied issues of external sovereign default risk or de-facto default on domestic debt via inflation.[25] Interest on domestic sovereign default risk has been motivated by the seminal empirical study of Reinhart and Rogoff (2011), which documents events of outright default on domestic public debt in a cross-country historical dataset going back to 1750, and by the turbulence in government debt markets that has affected the Eurozone since 2010.[26] Reinhart and Rogoff noted that the literature has paid little attention to domestic sovereign default, and hence their choice to title their paper *The Forgotten History of Domestic Debt*. As we document below, the situation has changed somewhat recently, but relatively speaking the study of domestic government defaults remains largely unchartered territory.

The framework on which we base most of our analysis in this Section is the one developed by D'Erasmo and Mendoza (2013) and D'Erasmo and Mendoza (2014). The main difference with external default models is in that the payoff of the government making the default decision includes the utility of agents who are government bond holders. Thus, we analyze the optimal default decision of a government unable to commit to repay the debt it has placed with domestic creditors in an environment with incomplete markets. Default is non-discriminatory, because the government cannot discriminate across any of its creditors when it defaults. There is explicit aggregate risk in the form of shocks to government outlays, and also implicit in the form of default risk. The government responds to distributional incentives affecting the welfare of heterogeneous, risk-averse agents. Default is useful as a vehicle for redistribution across agents, but it also has costs related to the reduced ability to smooth taxation, and, in long-horizon environments, to the loss of access to the asset used for self-insurance. In this framework, public debt is sustainable when it is supported by the optimal debt-issuance plans of the government. Sustainable debt factors in the risk of default, which implies paying positive risk premia on current debt issuance when future default is possible, and becomes unsustainable

[25] External default has been an issue of perennial interest in the literature, including seminal contributions like Eaton and Gersovitz (1981). The field became very active again, and with a particular interest in quantitative analysis, in the aftermath of the emerging markets crises of the 1990s (e.g. Aguiar and Gopinath (2006), Arellano (2008), Pitchford and Wright (2012), Yue (2010), Mendoza and Yue (2012)). Panizza, Sturzenegger, and Zettelmeyer (2009), Tomz and Wright (2012) and Aguiar and Amador (2014) provide recent surveys of this literature, and there is also a Chapter in this volume dedicated to the topic.

[26] Reinhart and Rogoff identified 68 outright domestic default episodes, which occurred via mechanisms such as forcible conversions, lower coupon rates, unilateral reductions of principal, and suspensions of payments.

when default becomes the optimal choice.

For simplicity, we develop the argument using D'Erasmo and Mendoza's (2013) two-period model, which highlights the importance of the distributional incentives of default at the expense of setting aside endogenous default costs due to the loss of access to self-insurance assets. D'Erasmo and Mendoza (2014) and Dovis, Golosov, and Shourideh (2014) study the role of distributional incentives to default on domestic debt, and the use of public debt in infinite horizon models with domestic agent heterogeneity. The two differ in that Dovis, Golosov, and Shourideh (2014) assume complete domestic asset markets, which removes the role of public debt as providing social insurance for domestic agents. In addition, they focus on the solution to the Ramsey problem, in which default is not observed along the equilibrium path. D'Erasmo and Mendoza study an economy with incomplete markets, which turns the loss of the vehicle for self-insurance, and the severity of the associated liquidity constraints, into an endogenous cost of default that plays a central role in their results. They also solve for Markov-perfect equilibria in which default is possible as an equilibrium outcome.

The model we examine is also related to the literature that analyzes the role of public debt as a self-insurance mechanism and a tool for altering consumption dispersion in heterogeneous-agents models without default (e.g. Aiyagari and McGrattan (1998), Golosov and Sargent (2012), Azzimonti, de Francisco, and Quadrini (2014), Floden (2001) , Heathcote (2005) and Aiyagari, Marcet, Sargent, and Seppala (2002)). A recent article by Pouzo and Presno (2014) introduces the possibility of default into models in this class. They study optimal taxation and public debt dynamics in a representative-agent setup similar to Aiyagari, Marcet, Sargent, and Seppala (2002) but allowing for default and renegotiation.

The recent interest in domestic sovereign default includes a strand of literature focusing on the consequences of default on domestic agents, its relation with secondary markets, discriminatory v. nondiscriminatory default, and the role of domestic debt in providing liquidity to the corporate sector (see Guembel and Sussman (2009), Broner, Martin, and Ventura (2010), Broner and Ventura (2011), Gennaioli, Martin, and Rossi (2014), Basu (2009), Brutti (2011), Mengus (2014) and Di Casola and Sichlimiris (2014)). There are also some recent studies motivated by the 2008 financial crisis that focus on the interaction between sovereign debt and domestic financial institutions such as Sosa-Padilla (2012), Bocola (2014), Boz, D'Erasmo, and Durdu (2014) and Perez (2015).

4.1 Model Structure

Consider a two-period economy $t = 0, 1$ inhabited by a continuum of agents with aggregate unit measure. All agents have the same preferences, which are given by:

$$u(c_0) + \beta E[u(c_1)], \qquad u(c) = \frac{c^{1-\sigma}}{1-\sigma}$$

where $\beta \in (0, 1)$ is the discount factor and c_t for $t = 0, 1$ is individual consumption. The utility function $u(\cdot)$ takes the standard CRRA form.

All agents receive a non-stochastic endowment y each period and pay lump-sum taxes τ_t, which are uniform across agents. Taxes and newly-issued government debt are used to pay for government consumption g_t and repayment of outstanding government debt. The (exogenous) initial supply of outstanding government bonds at $t = 0$ is denoted B_0. Agents differ in their initial wealth position, which is characterized by their holdings of government debt at the beginning of the first period.[27] Given B_0, the initial wealth distribution

[27] Andreasen, Sandleris, and der Ghote (2011), Ferriere (2014) and Jeon and Kabukcuoglu (2014) study environments in which domestic income heterogeneity plays a central role in the determination of external defaults.

is defined by a fraction γ of households who are the L-type individuals with initial bond holdings b_0^L, and a fraction $(1-\gamma)$ who are the H-types and hold b_0^H, where $b_0^H = \frac{B_0 - \gamma b_0^L}{1-\gamma} \geq b_0^L \geq 0$. This value of b_0^H is the amount consistent with market-clearing in the government bond market at $t = 0$, since we are assuming that the debt is entirely held by domestic agents. The initial distribution of wealth is exogenous, but the distribution at the beginning of the second period is endogenously determined by the agents' savings choices of the first period.

The budget constraints of the two types of households in the first period are given by:

$$c_0^i + q_0 b_1^i = y + b_0^i - \tau_0 \quad \text{for } i = L, H. \tag{10}$$

Agents collect the payout on their initial holdings of government debt (b_0^i), receive endowment income y, and pay lump-sum taxes τ_0. These net-of-tax resources are used to pay for consumption and purchases of new government bonds b_1^i. Agents are not allowed to take short positions in government bonds, which is equivalent to assuming that bond purchases must satisfy the familiar no-borrowing condition often used in heterogeneous-agents models: $b_1^i \geq 0$.

The budget constraints in the second period differ depending on whether the government defaults or not. If the government repays, the budget constraints take the standard form:

$$c_1^i = y + b_1^i - \tau_1 \quad \text{for } i = L, H. \tag{11}$$

If the government defaults, there is no repayment on the outstanding debt, and the agents' budget constraints are:

$$c_1^i = (1 - \phi(g_1))y - \tau_1 \quad \text{for } i = L, H. \tag{12}$$

As is standard in the external sovereign default literature, we allow for default to impose an exogenous cost that reduces income by a fraction ϕ. This cost is often modeled as a function of the realization of a stochastic endowment income, but since income is constant in this setup, we model it as a function of the realization of government expenditures in the second period g_1. In particular, the cost is a non-increasing, step-wise function: $\phi(g_1) \geq 0$, with $\phi'(g_1) \leq 0$ for $g_1 \leq \overline{g}_1$, $\phi'(g_1) = 0$ otherwise, and $\phi''(g_1) = 0$. Hence, $\overline{g}_1$ is a threshold high value of g_1 above which the marginal cost of default is zero. This formulation is analogous to the step-wise default cost as a function of income proposed by Arellano (2008) and now widely used in the external default literature, and it also captures the idea of asymmetric costs of tax collection (see Barro (1979) and Calvo (1988)). Note, however, that for the model to support equilibria with debt under a utilitarian government all we need is $\phi(g_1) > 0$. The additional structure is useful for the quantitative analysis and for making it easier to compare the model with the standard external default models.[28]

At the beginning of $t = 0$, the government has outstanding debt B_0 and can issue one-period, non-state contingent discount bonds $B_1 \in \mathcal{B} \equiv [0, \infty)$ at the price $q_0 \geq 0$. Each period it collects lump-sum revenues τ_t and pays for outlays g_t. Since g_0 is known at the beginning of the first period, the relevant uncertainty with respect to government expenditures is for g_1, which follows a log-normal distribution $N((1-\rho_g)\mu_g + \rho_g \ln(g_0), \frac{\sigma_g^2}{(1-\rho_g^2)})$.[29] We do not restrict the sign of τ_t, so $\tau_t < 0$ represents lump-sum transfers.[30]

[28] In external default models, the non-linear cost makes default more costly in "good" states, which alters default incentives to make default more frequent in "bad" states, and it also contributes to support higher debt levels.

[29] This is similar to an AR(1) process and allows us to control the correlation between g_0 and g_1 via ρ_g, the mean of the shock via μ_g and the variance of the unpredicted portion via σ_g^2. Note that if $\ln(g_0) = \mu_g$, $g_1 \sim N(\mu_g, \frac{\sigma_g^2}{(1-\rho_g^2)})$.

[30] Some studies in the sovereign debt literature have examined models that include tax and expenditure policies, as well as settings with foreign and domestic lenders, but always maintaining the representative agent assumption (e.g. Cuadra, J., and H. (2010)), Vasishtha (2010) and more recently Dias, Richmond, and Wright (2012) have examined the benefits of debt relief from the perspective of a *global* social planner with utilitarian preferences). Also in this literature, and closely related, is the work of Aguiar and Amador (2013) who analyze the interaction between public debt, taxes and default risk and Lorenzoni and Werning (2013) who study the dynamics of debt and interest rates in a model where default is driven by insolvency and debt issuance driven by a fiscal rule.

At equilibrium, the price of debt issued in the first period must be such that the government bond market clears:

$$B_t = \gamma b_t^L + (1-\gamma) b_t^H \quad \text{for } t = 0, 1. \tag{13}$$

This condition is satisfied by construction in period 0. In period 1, however, the price moves endogenously to clear the market.

The government has the option to default at $t = 1$. The default decision is denoted by $d_1 \in \{0, 1\}$ where $d_1 = 0$ implies repayment. The government evaluates the values of repayment and default using welfare weight ω for $L-$type agents and $1 - \omega$ for $H-$type agents. This specification encompasses cases in which, for political reasons for example, the welfare weights are biased toward a particular type so $\omega \neq \gamma$ or the case in which the government acts as a benevolent planner in which $\omega = \gamma$.[31] At the moment of default, the government evaluates welfare using the following function:

$$\omega u(c_1^L) + (1-\omega) u(c_1^H).$$

At $t = 0$, the government budget constraint is

$$\tau_0 = g_0 + B_0 - q_0 B_1. \tag{14}$$

The level of taxes in period 1 is determined after the default decision. If the government repays, taxes are set to satisfy the following government budget constraint:

$$\tau_1^{d_1=0} = g_1 + B_1. \tag{15}$$

Notice that, since this is a two-period model, equilibrium requires that there are no outstanding assets at the end of period 1 (i.e. $b_2^i = B_2 = 0$ and $q_1 = 0$). If the government defaults, taxes are simply set to pay for government purchases:

$$\tau_1^{d_1=1} = g_1. \tag{16}$$

The analysis of the model's equilibrium proceeds in three stages. First, we characterize the households' optimal savings problem and determine their payoff (or value) functions, taking as given the government debt, taxes and default decision. Second, we study how optimal government taxes and the default decision are determined. Third, we examine the optimal choice of debt issuance that internalizes the outcomes of the first two stages. We characterize these problems as functions of B_1, g_1, γ and ω, keeping the initial conditions (g_0, B_0, b_0^L) as exogenous parameters. Hence, for given γ and ω, we can index the value of a household as of $t = 0$, before g_1 is realized, as a function of $\{B_1\}$. Given this, the level of taxes τ_0 is determined by the government budget constraint once the equilibrium bond price q_0 is set. Bond prices are forward looking and depend on the default decision of the government in period 1,which will be given by the decision rule $d(B_1, g_1, \gamma, \omega)$.

[31] This relates to the literature on political economy and sovereign default, which largely focuses on external default (e.g. Amador (2003), Dixit and Londregan (2000), D'Erasmo (2011), Guembel and Sussman (2009), Hatchondo, Martinez, and Sapriza (2009) and Tabellini (1991)), but includes studies like those of Alesina and Tabellini (1990) and Aghion and Bolton (1990) that focus on political economy aspects of government debt in a closed economy, and the work of Aguiar, Amador, Farhi, and Gopinath (2013) on optimal policy in a monetary union subject to self-fulfilling debt crises.

4.2 Optimization Problems and Equilibrium

Given B_1, γ, and ω a household with initial debt holdings b_0^i for $i = L, H$ chooses b_1^i by solving this maximization problem:

$$v^i(B_1,\gamma,\omega) = \max_{b_1^i} \Big\{ u(y + b_0^i - q_0 b_1^i - \tau_0) + \beta E_{g_1}\Big[(1-d_1)u(y + b_1^i - \tau_1^{d_1=0}) + d_1 u(y(1-\phi(g_1)) - \tau_1^{d_1=1})\Big]\Big\}, \quad (17)$$

subject to $b_1^i \geq 0$. The term $E_{g_1}[.]$ represents the expected payoff across the repayment and default states in period 1. Notice in particular that the payoff in case of default does not depend on the level of individual debt holdings (b_1^i), reflecting the fact that the government cannot discriminate across households when it defaults.

A key feature of the above problem is that agents take into account the possibility of default in choosing their optimal bond holdings. The first-order condition, evaluated at the equilibrium level of taxes, yields this Euler equation:

$$u'(c_0^i) \geq \beta(1/q_0)E_{g_1}\left[u'(y - g_1 + b_1^i - B_1)(1 - d_1(B_1, g_1, \gamma))\right], \ = \ \text{if} \ \ b_1^i > 0 \quad (18)$$

In states in which, given (B_1, γ, ω), the value of g_1 is such that the government chooses to default ($d_1(B_1, g_1, \gamma, \omega) = 1$), the marginal benefit of an extra unit of debt is zero.[32] Thus, conditional on B_1, a larger default set (i.e. a larger set of values of g_1 such that the government defaults), implies that the expected marginal benefit of an extra unit of savings decreases. As a result, everything else equal, a higher default probability results in a lower demand for government bonds, a lower equilibrium bond price, and higher taxes. This has important redistributive implications, because when choosing the optimal debt issuance, the government will internalize how, by altering the bond supply, it affects the expected probability of default and the equilibrium bond prices. Note also that from the agents' perspective, the default choice $d_1(B_1, g_1, \gamma, \omega)$ is independent of b_1^i.

The above Euler equation is useful for highlighting some important properties of the equilibrium pricing function of bonds:

1. The premium over a world risk-free rate (defined as q_0/β, where $1/\beta$ can be viewed as a hypothetical opportunity cost of funds for an investor, analogous to the role played by the world interest rate in the standard external default model) generally differs from the default probability for two reasons: (a) agents are risk averse, and (b) in the repayment state, agents face higher taxes, whereas in the standard model investors are not taxed to repay the debt. For agents with positive bond holdings, the above optimality condition implies that the premium over the risk-free rate is $E_{g_1}\left[u'(y - g_1 + b_1^i - B_1)(1 - d_1)/u'(c_0^i)\right]$.

2. If the Euler equation for $H-$type agents holds with equality (i.e., $b_1^H > 0$) and $L-$type agents are *credit constrained* (i.e., $b_1^L = 0$), the $H-$type agents are the marginal investor and their Euler equation can be used to derive the equilibrium price.

3. For sufficiently high values of B_1, γ or $1 - \omega$ the government chooses $d_1(B_1, g_1, \gamma, \omega) = 1$ for all g_1. In these cases, the expected marginal benefit of purchasing government bonds vanishes from the agents' Euler equation, and hence the equilibrium for that B_1 does not exist, since agents would not be willing to buy debt at any finite price.[33]

[32] Utility in the case of default equals $u(y(1-\phi(g_1)) - g_1)$, which is independent of b_1^i.

[33] This result is similar to the result in standard models of external default showing that rationing emerges at t for debt levels so high that the government would choose default at all possible income realizations in $t+1$.

The equilibrium bond pricing functions $q_0(B_1, \gamma, \omega)$, which returns bond prices for which, as long as consumption for all agents is non-negative and the default probability of the government is less than 1, the following market-clearing condition holds:

$$B_1 = \gamma b_1^L(B_1, \gamma, \omega) + (1-\gamma) b_1^H(B_1, \gamma, \omega), \tag{19}$$

where B_1 in the left-hand-side of this expression represents the public bonds supply, and the right-hand-side is the aggregate government bond demand.

As explained earlier, we analyze the government's problem following a backward induction strategy by studying first the default decision problem in the final period $t = 1$, followed by the optimal debt issuance choice at $t = 0$.

Government Default Decision at $t = 1$

At $t = 1$, the government chooses to default or not by solving this optimization problem:

$$\max_{d \in \{0,1\}} \left\{ W_1^{d=0}(B_1, g_1, \gamma, \omega), W_1^{d=1}(g_1, \gamma, \omega) \right\}, \tag{20}$$

where $W_1^{d=0}(B_1, g_1, \gamma, \omega)$ and $W_1^{d=1}(B_1, g_1, \gamma, \omega)$ denote the values of the social welfare function at the beginning of period 1 in the case of repayment and default respectively. Using the government budget constraint to substitute for $\tau_1^{d=0}$ and $\tau_1^{d=1}$, the government's payoffs can be expressed as:

$$W_1^{d=0}(B_1, g_1, \gamma, \omega) = \omega u(y - g_1 + b_1^L - B_1) + (1-\omega) u(y - g_1 + b_1^H - B_1) \tag{21}$$

and

$$W_1^{d=1}(g_1, \gamma, \omega) = u(y(1 - \phi(g_1)) - g_1). \tag{22}$$

Combining these payoff functions, if follows that the government defaults if this condition holds:

$$\omega \left[u(y - g_1 + \overbrace{(b_1^L - B_1)}^{\leq 0}) - u(y(1-\phi(g_1)) - g_1) \right] + \tag{23}$$

$$(1-\omega) \left[u(y - g_1 + \overbrace{(b_1^H - B_1)}^{\geq 0}) - u(y(1-\phi(g_1)) - g_1) \right] \leq 0$$

Notice that all agents forego g_1 of their income to government absorption regardless of the default choice. Moreover, debt repayment reduces consumption and welfare of L types and rises them for H types, whereas default implies the same consumption and utility for both types of agents.

The distributional effects of a default are implicit in condition (23). Given that debt repayment affects the cash-in-hand for consumption of low- and high-wealth agents according to $(b_1^L - B_1) \leq 0$ and $(b_1^H - B_1) \geq 0$ respectively, it follows that, for a given B_1, the payoff under repayment allocates (weakly) lower welfare to L agents and higher to H agents, and that the gap between the two is larger the larger is B_1. Moreover, since the default payoffs are the same for both types of agents, this is also true of the *difference* in welfare under repayment v. default: It is higher for H agents than for L agents and it gets larger as B_1 rises. To induce default, however, it is necessary not only that L agents have a smaller difference in the payoffs of repayment v. default, but that the difference is negative (i.e. they must attain lower welfare under repayment than under default), which requires $B_1 > b_1^L + y\phi(g_1)$. This also implies that taxes under repayment need to be necessarily larger than under default, since $\tau_1^{d=0} - \tau_1^{d=1} = B_1$.

We can illustrate the distributional mechanism driving the default decision by comparing the utility levels associated with the consumption allocations of the default and repayment states with those that would be socially efficient. To this end, it is helpful to express the values of optimal debt holdings in period 1 as $b_1^L = B_1 - \epsilon$ and $b_1^H(\gamma) = B_1 + \frac{\gamma}{1-\gamma}\epsilon$, for some hypothetical decentralized allocation of debt holdings given by $\epsilon \in [0, B_1]$.[34] Consumption allocations under repayment would therefore be $c_1^L(\epsilon) = y - g_1 - \epsilon$ and $c_1^H(\gamma, \epsilon) = y - g_1 + \frac{\gamma}{1-\gamma}\epsilon$, so ϵ also determines the decentralized consumption dispersion.

The government payoff under repayment can be rewritten as:

$$W^{d=0}(\epsilon, g_1, \gamma, \omega) = \omega u(y - g_1 + \epsilon) + (1-\omega)u\left(y - g_1 + \frac{\gamma}{1-\gamma}\epsilon\right).$$

The efficient dispersion of consumption that the social planner would choose is characterized by the value of ϵ^{SP} that maximizes social welfare under repayment. In the particular case of $\omega = \gamma$ (i.e., when welfare weights coincide with the wealth distribution), ϵ^{SP} satisfies this first-order condition:

$$u'\left(y - g_1 + \frac{\gamma}{1-\gamma}\epsilon^{SP}\right) = u'\left(y - g_1 - \epsilon^{SP}\right). \tag{24}$$

Hence, the efficient allocations are characterized by zero consumption dispersion, because equal marginal utilities imply $c^{L,SP}{=}c^{H,SP} = y - g_1$, which is attained with $\epsilon^{SP} = 0$.

Continuing under the assumption that $\omega = \gamma$, consider now the government's default decision when default is costless ($\phi(g_1) = 0$). Given that the only policy instruments the government can use, other than the default decision, are non-state contingent debt and lump-sum taxes, it is straightforward to show that default will always be optimal. This is because default supports the socially efficient allocations in the decentralized equilibrium (i.e. it yields zero consumption dispersion with consumption levels $c^L{=}c^H = y - g_1$). This outcome is invariant to the values of B_1, g_1, γ and ϵ (over their relevant ranges). This result also implies, however, that the model without default costs cannot support equilibria with domestic debt subject to default risk, because default is always optimal.

The above scenario is depicted in Figure 11, which plots the social welfare function under repayment as a function of ϵ as the bell-shaped curve, and the social welfare under default (which is independent of ϵ), as the black dashed line. Clearly, the maximum welfare under repayment is attained when $\epsilon = 0$ which is also the efficient amount of consumption dispersion ϵ^{SP}. Moreover, since the relevant range of consumption dispersion is $\epsilon > 0$, welfare under repayment is decreasing in ϵ over the relevant range.

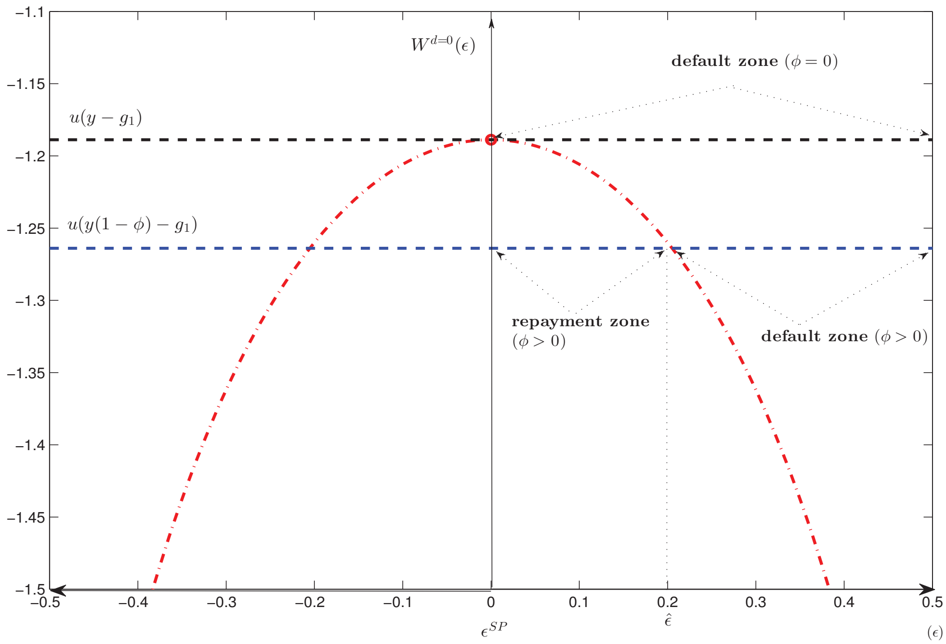
These results can be summarized as follows:

Result 1: *If $\phi(g_1) = 0$ for all g_1 and $\omega = \gamma$, then for any $\gamma \in (0, 1)$ and any (B_1, g_1), the social value of repayment $W^{d=0}(B_1, g_1, \gamma)$ is decreasing in ϵ and attains its maximum at the socially efficient point $\epsilon^{SP} = 0$ (i.e. when welfare equals $u(y - g_1)$). Hence, default is always optimal for any given decentralized consumption dispersion $\epsilon > 0$.*

The outcome is very different when default is costly. With $\phi(g_1) > 0$, default still yields zero consumption dispersion, but at lower levels of consumption and therefore utility, since consumption allocations under default are $c^L{=}c^H = (1-\phi(g_1))y - g_1$. This does not alter the result that the social optimum is $\epsilon^{SP} = 0$, but what changes is that default can no longer support the socially efficient consumption allocations. Instead, there is now a threshold amount of consumption dispersion in the decentralized equilibrium, $\widehat{\epsilon}(\gamma)$, which

[34] We take ϵ as given here because it helps us explain the intuition behind the distributional default incentives of the government, but ϵ is an equilibrium outcome of the model. Also, ϵ must be non-negative, otherwise H types would be the low-wealth agents.

Figure 11: Default Decision and Consumption Dispersion



varies with γ and such that for $\epsilon \geq \widehat{\epsilon}(\gamma)$ default is again optimal, but for lower ϵ repayment is now optimal. This is because when ϵ is below the threshold, repayment produces a level of social welfare higher than under default.

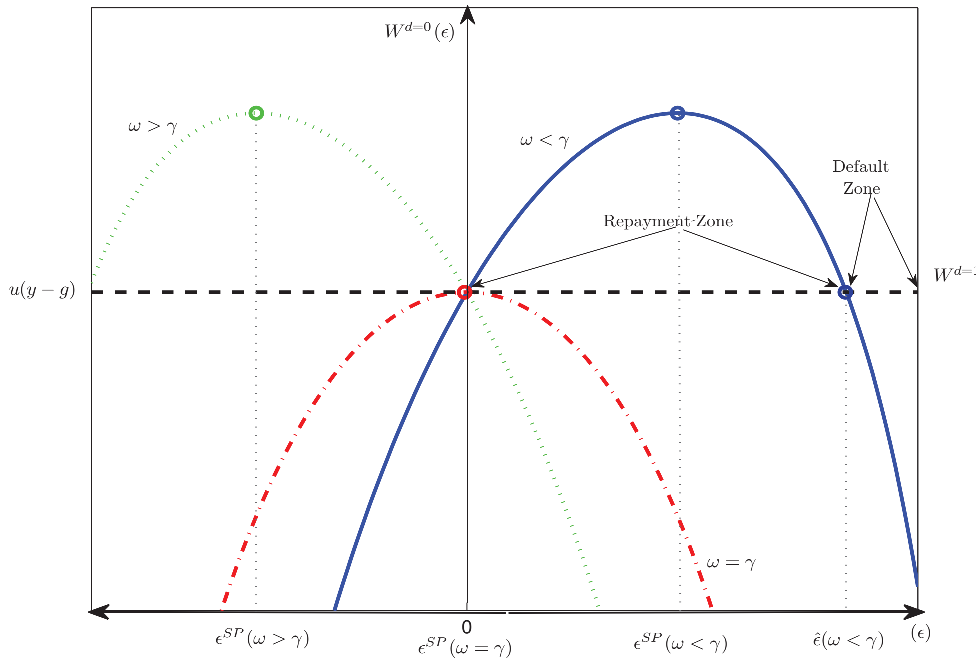
Figure 11 also illustrates this scenario. The default cost lowers the common level of utility of both types of agents, and hence of social welfare, in the default state (shown in the Figure as the blue dashed line), and $\widehat{\epsilon}(\gamma)$ is determined where social welfare under repayment and under default intersect. If the decentralized consumption dispersion with the debt market functioning (ϵ) is between 0 and less than $\widehat{\epsilon}(\gamma)$ then it is optimal for the government to repay. Intuitively, if consumption dispersion is not too large, the government prefers to repay because the income cost imposed on agents to remove consumption dispersion under default is too large. Moreover, as γ rises the domain of $W_1^{d=0}$ narrows, and thus $\widehat{\epsilon}(\gamma)$ falls and the interval of decentralized consumption dispersions that supports repayment narrows. This is natural because a higher γ causes the planner to weight more L-types in the social welfare function, which are agents with weakly lower utility in the repayment state.

These results can be summarized as follows:

Result 2: *If $\phi(g_1) > 0$, then for any $\gamma \in (0,1)$ and any (B_1, g_1), there is a threshold value of consumption dispersion $\widehat{\epsilon}(\gamma)$ such that the payoffs of repayment and default are equal: $W^{d=0}(B_1, g_1, \gamma) = u(y(1-\phi(g_1)) - g_1)$. The government repays if $\epsilon < \widehat{\epsilon}(\gamma)$ and defaults otherwise. Moreover, $\widehat{\epsilon}(\gamma)$ is decreasing in γ.*

Introducing a "political" bias in the welfare function of the government leads to interesting results. The key difference between the case where $\omega \neq \gamma$ v. the model with a utilitarian government ($\omega = \gamma$) is that it can support equilibria with debt subject to default risk even without default costs. Assuming $\phi(g_1) = 0$, there are two possible scenarios depending on the relative size of γ and ω. First, if $\omega > \gamma$, the planner again always chooses default as in the setup with $\omega = \gamma$. This is because for any $\epsilon > 0$, the decentralized consumption allocations feature $c^H > c^L$, while the planner's optimal consumption dispersion requires $c^H \leq c^L$, and hence

Figure 12: Default Decision with Non-Utilitarian Planner ($\phi = 0$)



ϵ^{SP} cannot be implemented. Default brings the planner the closest it can get to the payoff associated with ϵ^{SP} and hence it is always chosen.

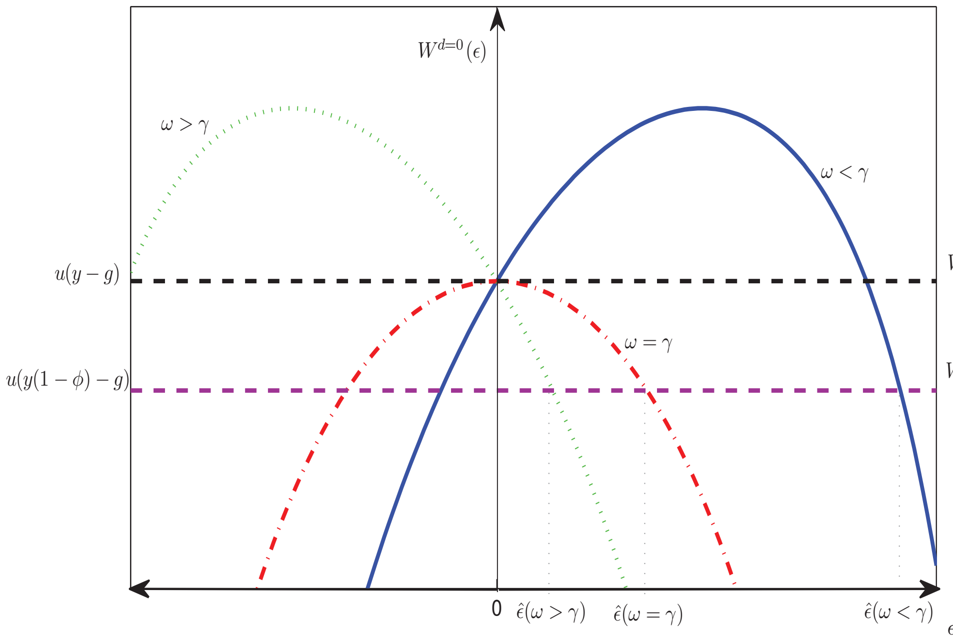
In the second scenario $\omega < \gamma$, which means that the political bias assigns more (less) weight to H (L) types than the fraction of each type of agents that actually exists. In this case, the model can support equilibria with debt even without default costs. In particular, there is a threshold consumption dispersion $\hat{\epsilon}$ such that default is optimal for $\epsilon \geq \hat{\epsilon}$, where $\hat{\epsilon}$ is the value of ϵ at which $W_1^{d=0}(\epsilon, g_1, \gamma, \omega)$ and $W_1^{d=1}(g_1)$ intersect. For $\epsilon < \hat{\epsilon}$, repayment is preferable because $W_1^{d=0}(\epsilon, g_1, \gamma, \omega) > W_1^{d=0}(g_1)$. Thus, without default costs, equilibria for which repayment is optimal require two conditions: (a) that the government's political bias favors bond holders ($\omega < \gamma$), *and* (b) that the debt holdings chosen by private agents do not produce consumption dispersion in excess of $\hat{\epsilon}$.

Figure 12 illustrates the outcomes just described. This Figure plots $W_1^{d=0}(\epsilon, g_1, \gamma, \omega)$ for $\omega \gtreqless \gamma$. The planner's default payoff and the values of ϵ^{SP} for $\omega \gtreqless \gamma$ are also identified in the plot. The vertical intercept of $W_1^{d=0}(\epsilon, g_1, \gamma, \omega)$ is always $W^{d=1}(g_1)$ for any values of ω and γ, because when $\epsilon = 0$ there is zero consumption dispersion and that is also the outcome under default. In addition, the bell-shaped form of $W_1^{d=0}(\epsilon, g_1, \gamma, \omega)$ follows from $u'(.) > 0, u''(.) < 0$.[35]

Take first the case with $\omega > \gamma$. In this case, the planner's payoff under repayment is the dotted bell curve. Here, $\epsilon^{SP} < 0$, because the optimality condition implies that the planner's optimal choice features $c^L > c^H$. Since default is the only instrument available to the government, however, these consumption allocations are not feasible, and by choosing default the government attains $W^{d=1}$, which is the highest feasible government payoff for any $\epsilon \geq 0$. In contrast, in the case with $\omega = \gamma$, for which the planner's payoff function is the dashed bell curve, the planner chooses $\epsilon^{SP} = 0$, and default attains exactly the same payoff,

[35] Note in particular that $\frac{\partial W_1^{d=0}(\epsilon, g_1, \gamma, \omega)}{\partial \epsilon} \gtreqless 0 \iff \frac{u'(c^H(\epsilon))}{u'(c^L(\epsilon))} \gtreqless (\frac{\omega}{\gamma})(\frac{1-\gamma}{1-\omega})$. Hence, the planner's payoff is increasing (decreasing) at values of ϵ that support sufficiently low (high) consumption dispersion so that $\frac{u'(c^H(\epsilon))}{u'(c^L(\epsilon))}$ is above (below) $(\frac{\omega}{\gamma})(\frac{1-\gamma}{1-\omega})$.

Figure 13: Default Decision with Non-Utilitarian Planner when $\phi(g_1) > 0$



so default is chosen. In short, if $\omega \geq \gamma$, the government always defaults for any decentralized distribution of debt holdings represented by $\epsilon > 0$, and thus equilibria with debt cannot be supported.

When $\omega < \gamma$, the planner's payoff is the continuous curve. The intersection of the downward-sloping segment of $W_1^{d=0}(\epsilon, g_1, \gamma, \omega)$ with $W^{d=1}$ determines the default threshold $\hat{\epsilon}$ such that default is optimal only in the *default zone* where $\epsilon \geq \hat{\epsilon}$. Default is still a second-best policy for the planner, because with it the planner cannot attain $W^{d=0}(\epsilon^{SP})$, it just gets the closest it can get. In contrast, the choice of repayment is preferable in the *repayment zone* where $\epsilon < \hat{\epsilon}$,, because in this zone $W_1^{d=0}(\epsilon, g_1, \gamma, \omega) > W^{d=1}(g_1)$.

Adding default costs to this political bias setup ($\phi(g_1) > 0$) makes it possible to support repayment equilibria even when $\omega \geq \gamma$. As Figure 13 shows, with default costs there are threshold values of consumption dispersion, $\hat{\epsilon}$, separating repayment from default zones for $\omega \lesseqgtr \gamma$.

It is also evident in Figure 13 that the range of values of ϵ for which repayment is chosen widens as γ rises relative to ω. Thus, when default is costly, equilibria with repayment require only the condition that the debt holdings chosen by private agents, which are implicit in ϵ, do not produce consumption dispersion larger than the value of $\hat{\epsilon}$ associated with a given (ω,γ) pair. Intuitively, the consumption of H-type agents must not exceed that of L-type agents by more than what $\hat{\epsilon}$ allows, because otherwise default is optimal.

Government Debt Issuance Decision at $t = 0$

We are now in a position to study how the government chooses the optimal amount of debt to issue in the initial period. These are the model's predicted sutainable debt levels, some of which will be optimally defaulted on depending on the realization of $g_1$in the second period. Both the government and the private sector are aware of this, so the debt levels that can be issued at equilibrium in the first period are traded at prices that can carry a default risk premium, which will be the case if for a given debt stock there are some values of g_1 for which default is the optimal choice in the second period.

Before studying the government's optimization problem, it is important to emphasize that in this model debt is mainly a mechanism for altering consumption dispersion across agents both within a period and across periods. In particular, consumption dispersion in each period and repayment state is given by:

$$\begin{aligned} c_0^H - c_0^L &= \frac{1}{1-\gamma}\left[B_0 - q_0(B_1,\gamma,\omega)B_1\right] \\ c_1^{H,d=0} - c_1^{L,d=0} &= \frac{1}{1-\gamma}B_1 \\ c_1^{H,d=1} - c_1^{L,d=1} &= 0. \end{aligned}$$

These expressions make it clear that, given B_0, issuing at least some debt ($B_1 > 0$) reduces consumption dispersion at $t = 0$ compared with no debt ($B_1 = 0$), but increases it at $t = 1$ if the government repays (*i.e.,* $d = 0$). Moreover, the use of debt as tool for redistribution of consumption at $t = 0$ is hampered by a Laffer curve relationship just like the distortionary taxes of the previous Section. In this case, the debt Laffer curve is defined by how the resources the government acquires by borrowing, $q_0(B_1, \gamma, \omega)B_1$, vary with the amount of debt issued, B_1. Starting from $B_1 = 0$, consumption dispersion at $t = 0$ falls as B_1 increases, but there is a critical positive value of B_1 beyond which it becomes an increasing function of debt.

At $t = 0$, the government chooses its debt policy internalizing the above effects, including the dependence of bond prices on the debt issuance choice, and their implications for social welfare. Formally, the government chooses B_1 so as to maximize the "indirect" social welfare function:

$$W_0(\gamma,\omega) = \max_{B_1}\left\{\omega v^L(B_1,\gamma,\omega) + (1-\omega)v^H(B_1,\gamma,\omega)\right\}. \tag{25}$$

where v^L and v^H are the private agents' value functions obtained from solving the problems defined in the Bellman equation (17) taking into account the government budget constraints and the equilibrium pricing function of bonds.

Focusing on the case with $\omega = \gamma$, we can gain some intuition about the solution of this maximization problem from its first-order condition (assuming that the relevant functions are differentiable):

$$u'(c_0^H) = u'(c_0^L) + \frac{\eta}{q_0(B_1,\gamma,\omega)\gamma}\left\{\beta E_{g_1}\left[\Delta d \Delta W_1\right] + \gamma \mu^L\right\}$$

where

$$\begin{aligned} \eta &\equiv q_0(B_1,\gamma,\omega)/\left(q_0'(B_1,\gamma,\omega)B_1\right) < 0, \\ \Delta d &\equiv d(B_1+\delta, g_1,\gamma) - d(B_1,g_1,\gamma) \geq 0, \quad \text{for } \delta > 0 \text{ small}, \\ \Delta W_1 &\equiv W_1^{d=1}(g_1,\gamma) - W_1^{d=0}(B_1,g_1,\gamma) \geq 0, \\ \mu^L &\equiv q_0(B_1,\gamma,\omega)u'(c_0^L) - \beta E_{g_1}\left[(1-d^1)u'(c_1^L)\right] > 0. \end{aligned}$$

In these expressions, η is the price elasticity of the demand for government bonds, $\Delta d \Delta W_1$ represents the marginal distributional benefit of a default, and μ^L is the shadow value of the borrowing constraint faced by L-type agents.

If both types of agents could be unconstrained in their savings decisions, so that in $\mu_L = 0$, and if there is no change in the risk of default (or assuming commitment to remove default risk entirely), so that $E_{g_1}[\Delta d \Delta W_1] = 0$, then the optimality condition simplifies to:

$$u'(c_0^H) = u'(c_0^L).$$

Hence, in this case the social planner would want to issue debt so as to equalize marginal utilities of consumption across agents at date 0, which requires simply setting B_1 to satisfy $q_0(B_1, \gamma, \omega)B_1 = B_0$. However, this scenario cannot be sustained as an equilibrium outcome, because at equilibrium if H-type agents are unconstrained, then L-types are constrained (i.e. $\mu_L > 0$). In this case, and still assuming no change in default risk or a government committed to repay, the optimality condition becomes:

$$u'(c_0^H) = u'(c_0^L) + \frac{\eta \mu^L}{q_0(B_1, \gamma, \omega)}.$$

Since $\eta < 0$, this result implies $c_0^L < c_0^H$, because $u'(c_0^L) > u'(c_0^H)$. Thus, even with unchanged default risk or no default risk at all, the government's debt choice sets B_1 as needed to maintain an optimal, positive level of consumption dispersion, which is the one that supports an excess in marginal utility of L-type agents relative to H-type agents equal to $\frac{\eta \mu^L}{q_0(B_1, \gamma, \omega)}$. Moreover, since optimal consumption dispersion is positive, we can also ascertain that $B_0 > q_0(B_1, \gamma, \omega)B_1$, which using the government budget constraint implies that the government runs a primary surplus at $t = 0$. The government borrows resources, but less than it would need in order to eliminate all consumption dispersion (which requires zero primary balance).

The intuition for the optimality of issuing debt can be presented in terms of tax smoothing and savings: Date-0 consumption dispersion without debt issuance would be $B_0/(1 - \gamma)$, but this is more dispersion than what the government finds optimal, because by choosing $B_1 > 0$ the government provides tax smoothing (i.e. reduces date-0 taxes) for everyone, which in particular eases the L-type agents credit constraint, and provides also a desired vehicle of savings for H types. Thus, positive debt increases consumption of L types (since $c_0^L = y - g_0 - B_0 + q_0(B_1, \gamma, \omega)B_1$), and reduces consumption of H types (since $c_0^H = y - g_0 + \left(\frac{\gamma}{1-\gamma}\right)(B_0 - q_0(B_1, \gamma, \omega)B_1)$). But issuing debt (assuming repayment) also increases consumption dispersion a $t = 1$, since debt is then paid with higher taxes on all agents, while H agents collect also the debt repayment. Thus, the debt is being chosen optimally to trade off the social costs and benefits of reducing (increasing) date-0 consumption and increasing (reducing) date-1 consumption for rich (poor) agents. In doing so, the government internalizes the debt Laffer curve and the fact that additional debt lowers the price of bonds and helps reduce μ^L, which in turn reduces the government's optimal consumption dispersion.[36]

In the presence of default risk and if default risk changes near the optimal debt choice, the term $E_{g_1}[\Delta d \Delta W_1]$ enters in the government's optimality condition with a positive sign, which means the optimal gap in the date-0 marginal utilities across agents widens even more. Hence, the government's optimal choice of consumption dispersion for $t = 0$ is greater than without default risk, and the expected dispersion for $t = 1$ is lower, because in some states of the world the government will choose to default and consumption dispersion would then drop to zero. This also suggests that the government chooses a lower value of B_1 than in the absence of default risk, since date-0 consumptions are further apart. Moreover, the debt Laffer curve now plays a central role in the government's weakened incentives to borrow, because as default risk rises the price of bonds drops to zero faster and the resources available to reduce date-0 consumption dispersion peak at lower debt levels. In short, default risk reduces the government's ability to use non-state-contingent debt in order to reduce consumption dispersion.

In summary, the more constrained the $L-$types agents are (higher μ^L) or the higher the expected distributional benefit of a default (higher $E_{g_1}[\Delta d \Delta W_1]$), the larger the level of debt the government finds optimal to issue. Both of these mechanisms operate as pecuniary externalities: They matter only because the government debt choice can alter the equilibrium price of bonds which is taken as given by private agents.

For given values of γ and ω, a **Competitive Equilibrium with Optimal Debt and Default Policies** is a pair of value functions $v^i(B_1, \gamma, \omega)$ and decision rules $b^i(B_1, \gamma, \omega)$ for $i = L, H$, a government bond

[36] Note, however, that without default risk the Laffer curve has less curvature than with default risk, because $q_0^{ND}(B_1, \gamma) \geqq q_0(B_1, \gamma)$.

pricing function $q_0(B_1, \gamma, \omega)$ and a set of government policy functions $\tau_0(B_1, \gamma, \omega)$, $\tau_1^{d\in\{0,1\}}(B_1, g_1, \gamma, \omega)$, $d(B_1, g_1, \gamma, \omega)$, $B_1(\gamma, \omega)$ such that:

1. Given the pricing function and government policy functions, $v^i(B_1, \gamma, \omega)$ and $b_1^i(B_1, \gamma, \omega)$ solve the households' problem.
2. $q_0(B_1, \gamma, \omega)$ satisfies the market-clearing condition of the bond market (equation (19)).
3. The government default decision $d(B_1, g_1, \gamma, \omega)$ solves problem (20).
4. Taxes $\tau_0(B_1, \gamma, \omega)$ and $\tau_1^d(B_1, g_1, \gamma, \omega)$ are consistent with the government budget constraints.
5. The government debt policy $B_1(\gamma, \omega)$ solves problem (25).

4.3 Quantitative Analysis

We study the quantitative predictions of the model using a calibration based on European data. Since the model is simple, the goalis not to match closely the observed dynamics of debt and risk premia in Europe, but to show that a reasonable set of parameter values can support an equilibrium in which sustainable debt subject to default riskexists.[37] We also use this numerical analysis to study show the dispersion of initial wealth and the bias in government welfare affect sustainable debt.

4.3.1 Calibration

The model is calibrated to annual frequency, and most of the parameter values are set to match moments computed using European data. The parameter values that need to be set are the subjective discount factor β, the coefficient of relative risk aversion σ, the moments of the stochastic process of government expenditures $\{\mu_g, \rho_g, \sigma_g\}$, the initial levels of government debt and expenditures (B_0 g_0), the level of income y, the initial wealth of $L-$type agents b_0^L and the default cost function $\phi(g_1)$. The calibrated parameter values are summarized in Table 13. We evaluate equilibrium outcomes for values of γ and ω in the $[0, 1]$ interval. Data for the United States and Europe documented in D'Erasmo and Mendoza (2014a) suggest that the empirically relevant range for γ is $[0.55, 0.85]$. Hence, when taking a stance on a particular value of γ is useful we use $\gamma = 0.7$, which is the mid point of the plausible range.

The preference parameters are set to standard values: $\beta = 0.96$, $\sigma = 1$. We also assume for simplicity that $L-$types start with zero wealth, $b_0^L = 0$.[38]

We estimate an AR(1) process for government expenditures-GDP ratio (in logs) for France, Germany, Greece, Ireland, Italy, Spain and Portugal and set $\{\mu_g, \rho_g, \sigma_g\}$ to the estimated corresponding cross-country averages. This results in the following values $\mu_g = 0.1812$, $\rho_g = 0.8802$ and $\sigma_e = 0.017$. We set $g_0 = \mu_g$ and use the quadrature method proposed by Tauchen (1986) with 45 nodes in $G_1 \equiv \{\underline{g}_1, \ldots, \overline{g}_1\}$ to generate the realizations and transition probabilities of g_1.

[37] We solve the model following a backward-recursive strategy. First, for each pair $\{\gamma, \omega\}$ and taking as given B_1, we solve for the equilibrium price and default functions by iterating on $\{d_1, q_0, b_1^i\}$. Then, in the second stage we complete the solution of the equilibrium by finding the optimal choice of B_1 that solves the government's date-0 optimization problem (25). As explained earlier, for given values of B_1, γ and ω an equilibrium with debt will not exist if either the government finds it optimal to default on B_1 for all realizations of g_1 or if at the given B_1 the consumption of L types is non-positive.

[38] $\sigma = 1$ and $b_0^L = 0$ are also useful because under these assumptions we can obtain closed-form solutions and establish some results analytically.

Average income y is calibrated such that the model's aggregate resource constraint is consistent with the data when GDP is normalized to one. This implies that the value of the agents' aggregate endowment must equal GDP net of fixed capital investment and net exports, since the latter two are not explicitly modeled. The average for the period 1970-2012 for the same set of countries used to estimate the g_1 process implies $y = 0.7883$.[39]

We set the initial debt level $B_0 = 0.79$ so that at the maximum observed level of inequality in the data, $\gamma = 0.85$, there is at least one feasible level of B_1 when $\omega = \gamma$. We assume that the default cost takes the following form: $\phi(g_1) = \phi_0 + (\overline{g} - g_1)/y$, where $\overline{g}$ is calibrated to represent an "unusually large" realization of g_1 set equal to the largest realization in the Markov process of government expenditures, which is in turn set equal to 3 standard deviations from the mean (in logs).[40]

We calibrate ϕ_0 to match an estimate of the observed frequency of *domestic* defaults. According to Reinhart and Rogoff (2011), historically, domestic defaults are about 1/4 as frequent as external defaults (68 domestic v. 250 external in their data since 1750). Since the probability of an external default has been estimated in the range of 3 to 5 percent (see, for example, Arellano (2008)), the probability of a domestic default is about 1 percent. The model is close to this default frequency on average when solved over the empirically relevant range of γ's ($\gamma \in [0.55, 0.85]$) if we set $\phi_0 = 0.02$. Note, however, that the calibration of ϕ_0 and B_0 to match their corresponding targets needs to be done jointly by repeatedly solving the model until both targets are well approximated.

4.3.2 Utilitarian Government ($\omega = \gamma$)

We study first a set of results obtained under the assumption $\omega = \gamma$, because the utilitarian government is a natural benchmark. Since the default decision of the government derives from the agents' utility under the repayment and default alternatives at $t = 1$, it is useful to map the ordinal utility measures into cardinal measures by computing "individual welfare gains of default," which are standard consumption-equivalent values that equalize utility under default and repayment. Given the CRRA functional form, the individual welfare gains of default reduce simply to the percent changes in consumption across the default and no-default states of each agent at $t = 1$:

$$\alpha^i(B_1, g_1, \gamma) = \frac{c_1^{i,d=1}(B_1, g_1, \gamma)}{c_1^{i,d=0}(B_1, g_1, \gamma)} - 1 = \frac{(1 - \phi(g_1))y - g_1}{y - g_1 + b_1^i - B_1} - 1$$

A positive (negative) value of $\alpha^i(B_1, g_1, \gamma)$ implies that agent i prefers government default (repayment) by an amount equivalent to an increase (cut) of $\alpha^i(\cdot)$ percent in consumption. The individual welfare gains of default are aggregated using γ to obtain the utilitarian representation of the social welfare gain of default:

$$\overline{\alpha}(B_1, g_1, \gamma) = \gamma\alpha^L(B_1, g_1, \gamma) + (1 - \gamma)\alpha^H(B_1, g_1, \gamma).$$

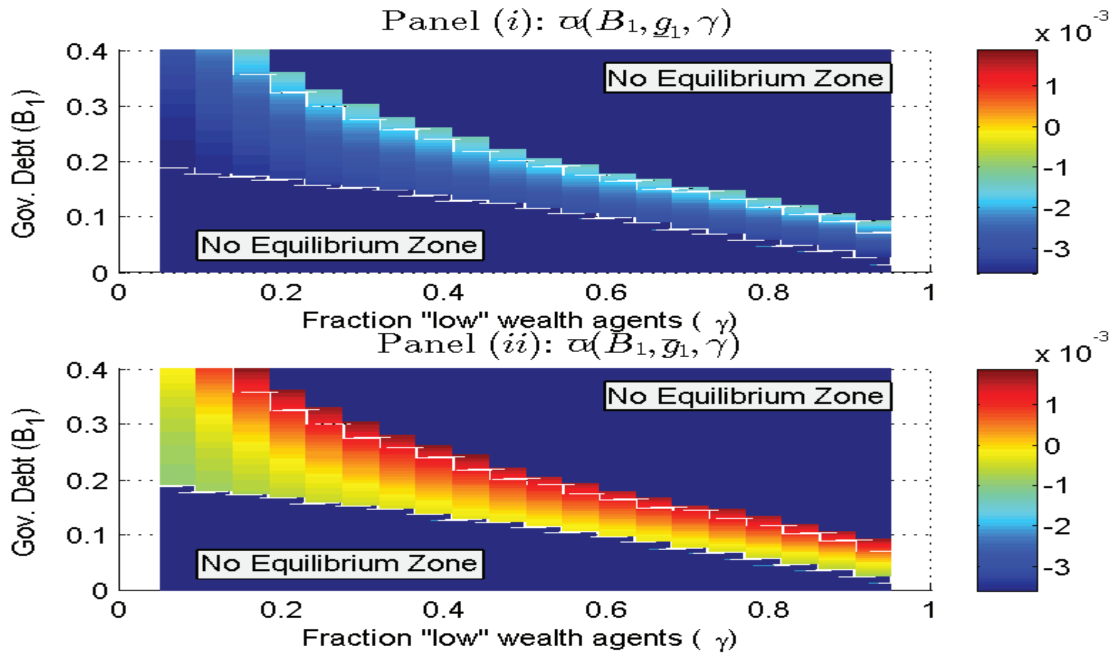
A positive value indicates that default induces a social welfare gain and a negative value a loss.

Figure 14 shows two intensity plots of the social welfare gain of default for the ranges of values of B_1 and γ in the vertical and horizontal axes respectively. Panel (i) is for a low value of government purchases, $\underline{g}_1$,

[39] Note also that under this calibration of y and the Markov process of g_1, the gap $y - g_1$ is always positive, even for $g_1 = \overline{g}_1$, which in turn guarantees $c_1^H > 0$ in all repayment states.

[40] This cost function shares a key feature of the default cost functions widely used in the external default literature to align default incentives so as to support higher debt ratios and trigger default during recessions (see Arellano (2008) and Mendoza and Yue (2012)): The default cost is an *increasing* function of disposable income ($y - g_1$). In addition, this formulation ensures that the agents' consumption during a default never goes above a given threshold.

Figure 14: Social Welfare Gains of Default $\overline{\alpha}(B_1, g_1, \gamma)$



Note: The intensity of the color or shading in these plots indicates the magnitude of the welfare gain according to the legend shown to the right of the plots. The regions shown in dark blue and marked as "No Equilibrium Zone", represent values of (B_1, γ) for which the debt market collapses and no equilibrium exists.

set 3 standard deviations below μ_g, and panel (ii) is for a high value $\overline{g}_1$ set 3 standard deviations above μ_g . "No Equilibrium Zone", represent values of (B_1, γ) for which the debt market collapses and no equilibrium exists.[41]

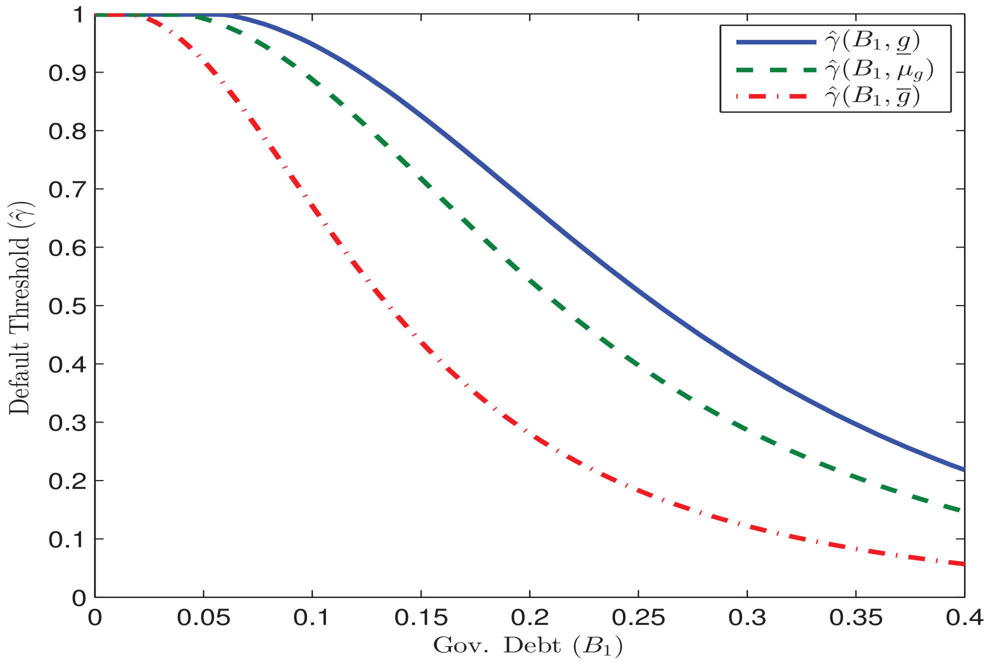
The area in which the social welfare gains of default are well defined in these intensity plots illustrates two of the key mechanisms driving the government's distributional incentives to default: First, fixing γ, the welfare gain of default is higher at higher levels of debt, or conversely the gain of repayment is lower. Second, keeping B_1 constant, the welfare gain of default is also increasing in γ (i.e. higher wealth concentration increases the welfare gain of default). This implies that lower levels of wealth dispersion are sufficient to trigger default at higher levels of debt.[42] For example, for a debt ratio of 20 percent of GDP ($B_1 = 0.20$) and $g_1 = \overline{g}_1$, social welfare is higher under repayment if $0 \leq \gamma \leq 0.25$ but it becomes higher under default if $0.25 < \gamma \leq 0.6$, and for higher γ there is no equilibrium because the government prefers default not only for $g_1 = \overline{g}_1$ but for all possible g_1. If instead the debt is 40 percent of GDP, then social welfare is higher under default for all the values of γ for which an equilibrium exists.

The two panels in Figure 14 differ in that panel (ii) displays a well-defined transition from a region in which repayment is socially optimal ($\overline{\alpha}(B_1, g_1, \gamma) < 0$) to one where default is optimal ($\overline{\alpha}(B_1, g_1, \gamma) > 0$) but in panel (i) the social welfare gain of default is never positive, so repayment is always optimal. This reflects

[41] Note that to determine if $c_0^L \leq 0$ at some (B_1, γ) we also need $q_0(B_1, \gamma)$, since combining the budget constraints of the L types and the government yields $c_0^L = y - g_0 - B_0 + q_0 B_1$. Hence, to evaluate this condition we take the given B_1 and use the H-types Euler equation and the market clearing condition to solve for $q_0(B_1, \gamma, \omega)$, and then determine if $y - g_0 - B_0 + q_0 B_1 \leq 0$, if this is true, then (B_1, γ) is in the lower no- equilibrium zone.

[42] Note that the cross-sectional variance of initial debt holdings is given by $Var(b) = B^2 \frac{\gamma}{1-\gamma}$ when $b_0^L = 0$. This implies that the cross-sectional coefficient of variation is equal to $CV(b) = \frac{\gamma}{1-\gamma}$, which is increasing in γ for $\gamma \leq 1/2$.

Figure 15: Default Threshold $\hat{\gamma}(B_1, g_1)$



the fact that higher g_1 also weakens the incentives to repay. In the "No Equilibrium Zone" in the upper right, there is no equilibrium because at the given γ the government chooses to default on the given B_1 for all values of g_1. In the "No Equilibrium Zone" in the lower left, there is no equilibrium because the given (B_1, γ) would yield $c_0^L \leq 0$, and so the government would not supply that particular B_1.

Consider next the government's default decision choice, which is driven by the sign of the social welfare gains of default. It is evident from Figure 14 that the government defaults the higher g_1 for given B_1 and γ, the higher B_1 for a given γ and g_1, or at higher γ at given B_1 and g_1. It follows then that we can compute a threshold value of γ such that the government is indifferent between defaulting and repaying in period $t = 1$ for a given (B_1, g_1). These indifference thresholds $(\hat{\gamma}(B_1, g_1))$ are plotted in Figure 15 against debt levels ranging from 0 to 0.4 for three values of government expenditures $\{\underline{g_1}, \mu_g, \overline{g}_1\}$. For any given (B_1, g_1), the government chooses to default if $\gamma \geq \hat{\gamma}$.

Figure 15 shows that the default threshold is decreasing in B_1. Hence, the government tolerates higher debt ratios without defaulting only if wealth concentration is sufficiently low. Also, default thresholds are decreasing in g_1, because the government has stronger incentives to default when government expenditures are higher (i.e. the threshold curves shift inward).[43] This last feature of $\hat{\gamma}$ is very important to determine equilibria with sustainable debt subject to default risk. If, for a given value of B_1, γ is higher than the curve representing $\hat{\gamma}$ for the lowest realization in the Markov process of g_1 (which is also the value of $\underline{g_1}$), the government defaults for sure and, as explained earlier, there is no sustainable debt at equilibrium. Alternatively, if for a given value of B_1, γ is lower than the curve representing $\hat{\gamma}$ for the highest realization of g_1 (which is the value of $\overline{g}_1$), the government repays for sure and debt would be issued effectively without default risk. Thus, for the model to support equilibria with sustainable debt subject to default risk, the optimal debt chosen by the government in the first period for a given γ must lie between these two extreme threshold curves. We show that this is the case later in this Section.

[43] $\hat{\gamma}$ approaches zero for B_1 sufficiently large, but in Figure 15 B_1 reaches 0.40 only for exposition purposes.

Next we examine the properties of the bond price function. The quantitative results, the details of which we omitt to save space, reflect the properties discussed in the model analysis:

1. *The equilibrium price is decreasing in* B_1 *for given* γ (the pricing functions shift downward as B_1 rises). This follows from a standard demand-and-supply argument: For a given γ, as the government borrows more, the price at which the H types are willing to demand the additional debt falls and the interest rate rises.

2. *Default risk reduces the price of bonds below the risk-free price and thus induces a risk premium.* Intuitively, when there is no default risk (i.e. for combinations of B_1 and γ such that the probability of default is zero) both prices are identical. However, as the probability of default rises, agents demand a premium in order to clear the bond market.

3. *Bond prices are a non-monotonic function of wealth dispersion*: When default risk is sufficiently low, bond prices are increasing in γ, but eventually they become a steep decreasing function of γ. Higher γ implies a more dispersed wealth distribution, so that H-type agents become a smaller fraction of the population, and hence they must demand a larger amount of debt per capita in order to clear the bond market (i.e. b_1^H increases with γ), which pushes bond prices up. While default risk is low this "demand composition effect" dominates and thus bond prices rise with γ, but as γ increases and default risk rises (since higher wealth dispersion strengthens default incentives), the growing risk premium becomes the dominating force (at about $\gamma > 0.5$) and produces bond prices that fall sharply as γ increases.

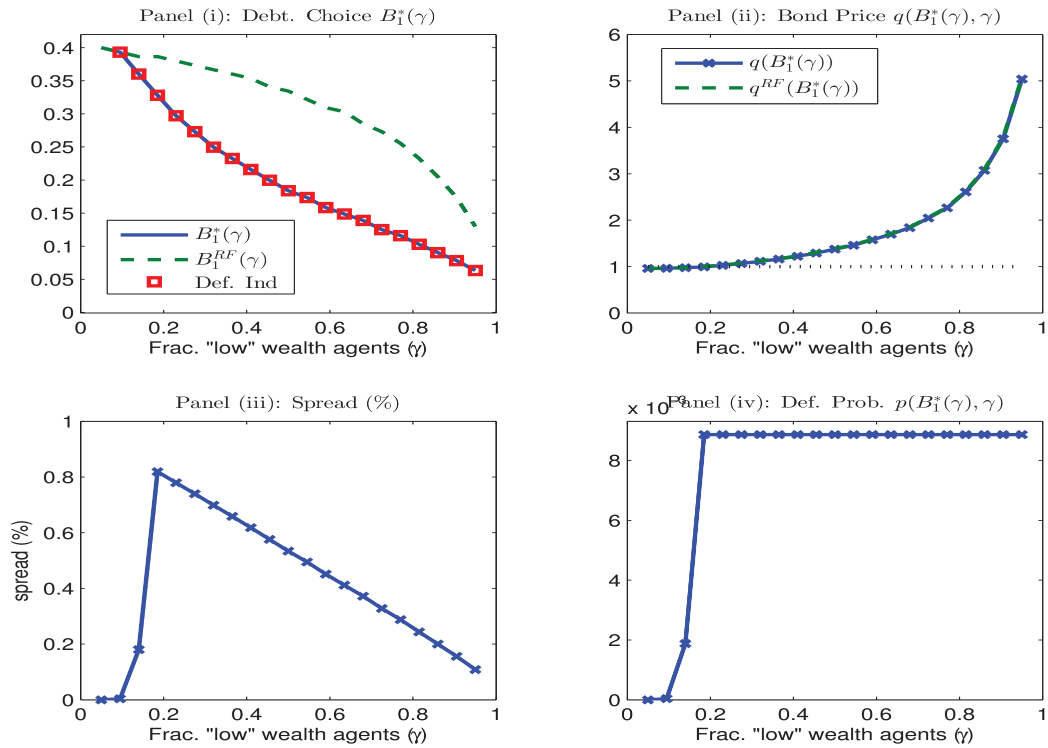
Finally we examine the numerical solutions of the model's competitive equilibrium with optimal debt and default policies,. The key element of the solution is the government's optimal choice of debt issuance in the first period (i.e. the optimal B_1 that solves problem (25)), which we solve for over a range of values of γ. Given this optimal debt, we can then use the functions that describe optimal debt demand plans of private agents in both periods, the government's default choice in period 1, bond prices, and default risk for *any* value of B_1 to determine the *equilibrium* values of all of the model's endogenous variables.

Figure 16 shows the four main components of the equilibrium: Panel (i) plots the optimal first-period debt issuance (i.e. the sustainable debt) of the model with default risk, $B_1^*(\gamma)$, and also, for comparison, in the case when the government is committed to repay so that the debt is risk free, $B_1^{RF}(\gamma)$. Panel (ii) shows the equilibrium debt prices that correspond to the optimal debt of the same two economies. Panel (iii) shows the default spread (the difference in the inverses of the bond prices). Panel (iv) shows the probability of default. Since in principle the government that has the option to default can still choose a debt level for which it could prefer to repay in all realizations of g_1, we identify with a square in Panel (i) the equilibria in which $B_1^*(\gamma)$ has a positive default probability. This is the case for all but the smallest value of gamma considered ($\gamma = 0.05$), in which the government sets $B_1^*(\gamma)$ at 40 percent of GDP with zero default probability.

Panel (i) shows that sustainable debt falls as γ increases in both the economy with default risk and the economy with a government committed to repay. This occurs because in both cases the government seeks to reallocate consumption across agents and across periods by altering the product $q(B_1)B_1$ optimally, and in doing this it internalizes the response of bond prices to its debt choice. As γ rises, this response is influenced by stronger default incentives and a stronger demand composition effect. The latter dominates in this quantitative experiment, because panel (ii) shows that the equilibrium bond prices always rise with γ. Hence,the government internalizes that as γ rises the demand composition effect strengthens demand for bonds, pushing bond prices higher, and as a result it can actually attain a higher $q(B_1)B_1$ by choosing lower B_1. This is a standard Laffer curve argument: In the upward slopping segment of this curve, increasing debt increases the amount of resources the government acquires by borrowing in the first period.

In the range of empirically relevant values of γ, sustainable debt ratios range from 20 to 32 percent of GDP without default risk and from 8 to 15 percent with default risk. Since the median in the European data

Figure 16: Equilibrium Optimal Government Debt Policy



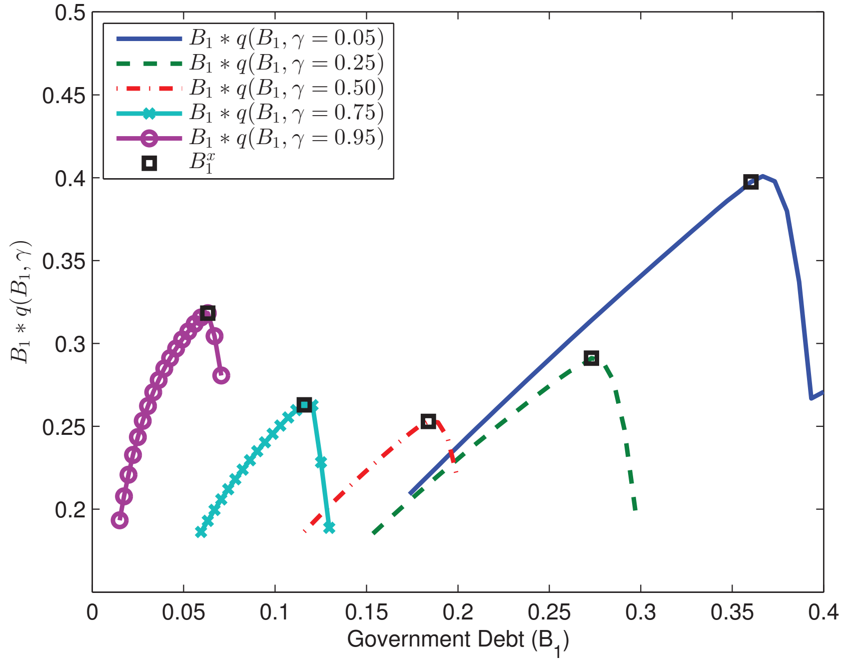
is 35 percent, these ratios are relatively low, but still they are notable given the simplicity of the two-period setup, with the inertia to reduce debt levels and constraints on feasible equilibrium debt positions discussed earlier. In particular, the model lacks the stronger income- and tax-smoothing effects and the self-insurance incentives of a longer life horizon (see Aiyagari and McGrattan (1998)), and the model has an upper bound on the optimal debt choice for $\gamma = [0, 1]$ lower than $B_0/(1 + \beta)$ (which is the upper bound as $\gamma \to 0$ in the absence of default risk).

Panel (*ii*) shows that bond prices of sustainable debt range from very low to very high as γ rises, including prices sharply above 1 that imply large negative real interest rates on public debt. In fact, as D'Erasmo and Mendoza (2014a) explain, equilibrium bond prices are similar and increasing in γ with or without default risk, because at equilibrium the government chooses debt positions for which default risk is low (see panel (*iv*)), and thus the demand composition effect that strengthens as γ rises dominates and yields bond prices increasing in γ and similar with or without default risk.

Panels (*iii*) and (*iv*) show that, in contrast with standard models of external default, in this model the default spread is neither similar to the probability of default nor does it have a monotonic relationship with it.[44] Both the spread and the default probability start at zero for $\gamma = 0.05$ because $B_1^*(0.05)$ has zero default probability. As γ increases up to 0.2, both the spread and the default probability of the sustainable debt are similar in magnitude and increase together, but for $\gamma > 0.2$ the spread falls with γ while the default probability remains unchanged around 0.9 percent. For $\gamma = 0.95$ the probability of default is 9 times larger than the spread (0.9 v. 0.1 percent).

[44] In the standard models, the two are similar and a monotonic function of each other because of the arbitrage condition of a representative risk-neutral investor.

Figure 17: Debt Laffer Curve



Note: Each curve is truncated at values of B_1 in the horizontal axis that are either low enough for $c_0^L \leq 0$ or high enough for default to be chosen for all realizations of g_1, because as noted before in these cases there is no equilibrium.

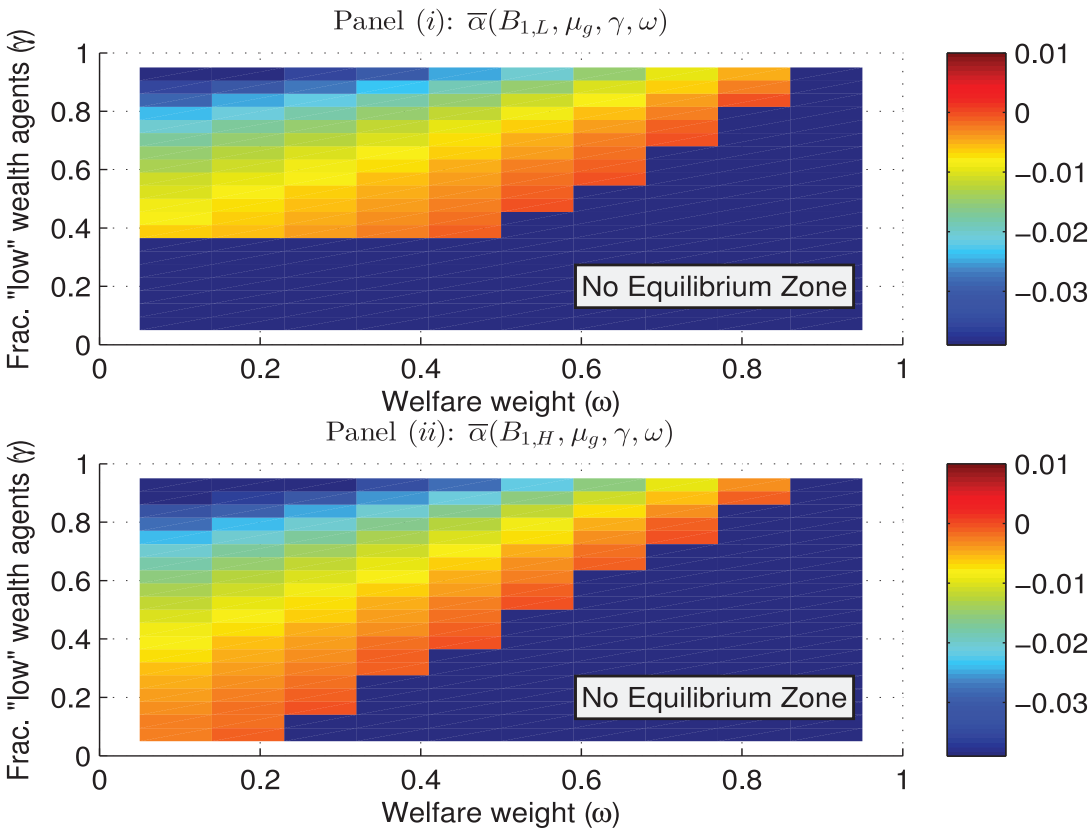
The role of the government's incentives to reallocate consumption across agents and across periods internalizing the response of bond prices when choosing debt can be illustrated further by examining the debt Laffer curve. Figure 17 shows debt Laffer curves for five values of γ in the [0.05,0.95] range.

In all but one case, the sustainable debt $B_1^*(\gamma)$ (i.e. the equilibrium debt chosen optimally by the government) is located at the maximum of the corresponding Laffer curve. In these cases, setting debt higher than at the maximum is suboptimal because default risk reduces bond prices sharply, moving the government to the downward-sloping segment of the Laffer curve. Setting debt lower than the maximum is also suboptimal, because then default risk is low and extra borrowing generates more resources since bond prices change little, leaving the government in the upward-sloping segment region of the Laffer curve. Thus, if the optimal debt has a nontrivial probability of default, the government's debt choice exhausts its ability to raise resources by borrowing. The exception is the case with $\gamma = 0.05$, in which $B_1^*(\gamma)$ has zero default probability. In this case, the government's optimal debt is to the left of the maximum of the Laffer curve, and thus the debt choice does not exhaust the government's ability to raise resources by borrowing. This also happens when the default probability is positive but negligible. For example, when $\gamma = 0.15$ the default probability is close to zero and the optimal debt choice is again slightly to the left of the maximum of the corresponding Laffer curve.

4.3.3 Biased Welfare Weights ($\omega \neq \gamma$)

The final experiment we conduct examines how the results change if we allow the weights of the government's payoff function to differ from the utilitarian weights. Figure 18 shows how the planner's welfare gain of default varies with ω and γ for two different levels of government debt ($B_{1,L} = 0.143$ and $B_{1,H} = 0.185$).

Figure 18: Planner's Welfare Gain of Default $\overline{\alpha}(B_1, g_1, \gamma, \omega)$



The no-equilibrium region, which exists for the same reasons as before, is shown in dark blue.

In line with the previous discussion, within the region where the equilibrium is well-defined, the planner's value of default increases monotonically as its preference for redistribution (ω) increases, keeping γ constant, and falls as actual wealth concentration (γ) rises, keeping ω constant. Because of this, the north-west and south-east corners in each of the panels present cases that are at very different positions on the preference-for-default spectrum. When ω is low, even for very high values of γ, the government prefers to repay (north-west corner), because the government puts relatively small weight on L-type agents. On the contrary, when ω is high, even for low levels of γ, a default is preferred. It is also interesting to note that as we move from Panel (i) to Panel (ii), so that government debt raises, the set of γ's and ω's such that the equilibrium exists or repayment is preferred (i.e. a negative $\overline{\alpha}(B_1, g_1, \gamma, \omega)$) expands. This is because as we increase the level of debt B_1, as long as the government does not choose to default for all g_1, the higher level of debt allows low-wealth agents to attain positive levels of consumption (since initial taxes are lower).

Panels $(i) - (iv)$ in Figure 19 display the model's equilibrium outcomes for the sustainable debt chosen by the government in the first period and the associated equilibrium bond prices, spreads and default probabilities under three possible values of ω, all plotted as functions of γ. It is important to note that along the blue curve of the utilitarian case both ω and γ effectively vary together because they are always equal to each other, while in the other two plots ω is fixed and γ varies. For this reason, the line corresponding to the ω_L case intersects the benchmark solution when $\gamma = 0.32$, and the one for ω_H intersects the benchmark when $\gamma = 0.50$.

Figure 19: Equilibrium of the Model with Political Bias for different values of ω

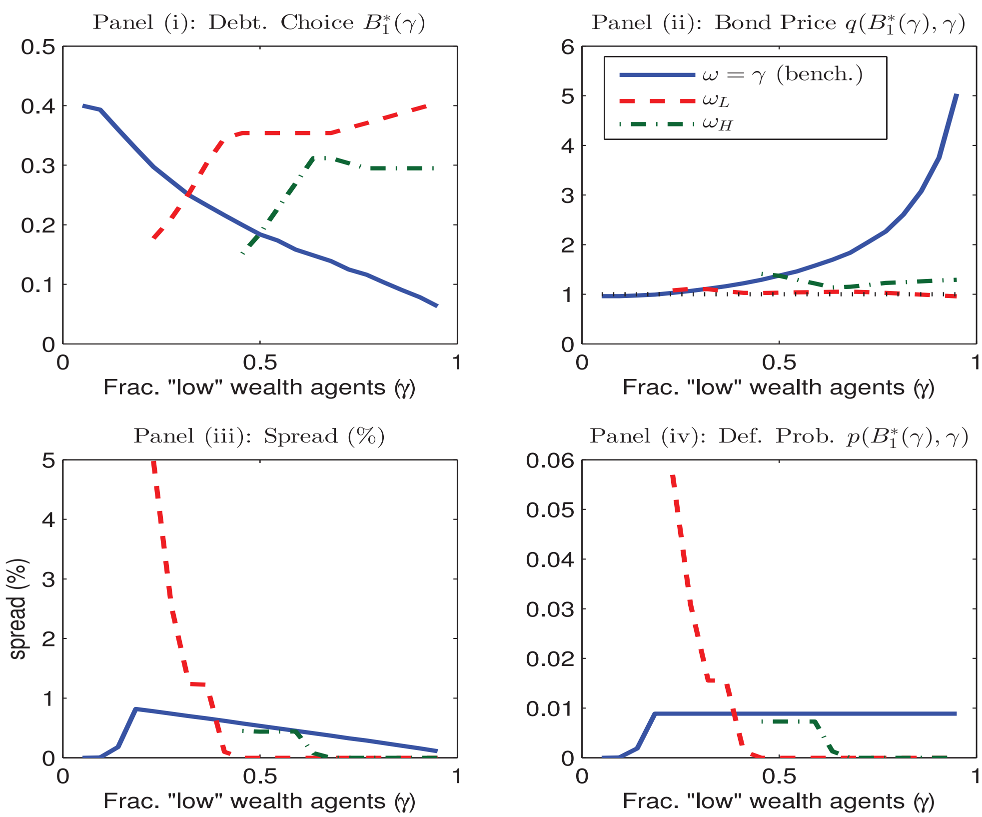


Figure 19 shows that the optimal debt level is increasing in γ. This is because the incentives to default grow weaker and the repayment zone widens as γ increases for a fixed value of ω. It is also interesting to note that in the ω_L and ω_H cases the equilibrium exists only for a small range of values of γ that are lower than ω. Without default costs each curve would be truncated exactly where γ equals either ω_H or ω_H, but since these simulations retain the default costs used in the utilitarian case, there can still be equilibria with debt for some lower values of γ (as explained earlier).

In this model with political bias, the government is still aiming to optimize debt by focusing on the resources it can reallocate across periods and agents, which are still determined by the debt Laffer curve $q_0(.)B_1$, and internalizing the response of bond prices to debt choices.[45] This relationship, however, behaves very differently than in the benchmark model, because now *higher* optimal debt is carried at increasing equilibrium bond prices, which leads the planner internalizing the price response to choose higher debt, whereas in the benchmark model *lower* optimal debt was carried at increasing equilibrium bond prices, which led the planner internalizing the price response to choose lower debt.

The behavior of equilibrium bond prices (panel (ii)) with either $\omega_L = 0.32$ or $\omega_H = 0.50$ differs markedly from the utilitarian case. In particular, the prices no longer display an increasing, convex shape, instead they are a relatively flat and non-monotonic function of γ. This occurs because the higher supply of bonds that the government finds optimal to provide offsets the demand composition effect that increases individual demand for bonds as γ rises.

The domestic default approach to study sustainable debt adds important insights to those obtained from the empirical and structural approaches, both of which assumed repayment commitment. In particular, panel (i) of Figure 16 shows that sustainable debt falls sharply once risk of default is present, even when it is very small, and that sustainable debt falls sharply with wealth inequality, because of the strengthened incentive to use default as a tool for redistribution. Hence, estimates of sustainable debt based on models in which the government is assumed to be committed to repay are likely to be too optimistic. Intuitively, one can infer that in the structural model, a given increase in the initial debt would be harder to offset with higher primary balances if the interest rate at which those primary balances are discounted rises with higher debt because of default risk. Moreover, the representative-agent assumption is also likely to lead to optimistic estimates of sustainable debt, because models of this class abstract from the strong incentives to use debt default as a tool for redistribution across heterogeneous agents. These incentives are weaker than in the model in practice, because tax and transfer policies that we did not include in the model can be used for redistribution as well. But when these other instruments have been exhausted, and if inequality in bond holdings is sufficiently concentrated, the incentives to default as vehicle for redistribution are likely to be strong.

A second important insight from this analaysis is that sustainable debt is higher if the government's payoff function weighs the welfare of bond hoders more heavily than their share of the wealth distribution, and can even exceed debt that is sustainable without default risk when the government has a utilitarian social welfare function. Interestingly, D'Erasmo and Mendoza (2013) show that low-wealth agents may also prefer equilibria where the government weights high-wealth agents more heavily, instead of acting as a utilitarian government, because higher debt stocks help relax their liquidity constraints.

The main caveat of this analysis is that, because it was based on a two-period model, it misses important endogenous costs of default that would be added to the model by simply introducing a longer life horizon. In this case, default costs due to the reduced ability to smooth taxation and consumption when the debt market closes, and due to the loss of access to the self-insurance vehicle and the associated tightening of

[45] When choosing B_1, the government takes into account that higher debt increases disposable income for L-type agents in the initial period but it also implies higher taxes in the second period (as long as default is not optimal). Thus, the government is willing to take on more debt when ω is lower.

liquidity constraints, can take up the role of the exogenous default costs and/or the political bias, enabling the model to improve its ability to account for key features of the data and sustain higher debt levels at nontrivial default premia. D'Erasmo and Mendoza (2014) examine a model with these features and study its quantitative implications.

5 Conclusions

What is a sustainable public debt? Assuming that the government is committed to repay, the answer is a debt that satisfies the intertemporal government budget constraint (i.e. a debt that is equal to the present discounted value of the primary fiscal balance). In this Chapter we showed that the traditional approach to debt sustainability analysis is flawed. This approach uses the steady-state government budget constraint to define sustainable debt as the annuity value of the primary balance, but it cannot establish if current or projected debt and primary balance dynamics are consistent with that debt level. We then discussed two approaches to study public debt sustainability under committment to repay: First, an empirical approach, based on a linear fiscal reaction function, according to which a positive, conditional response of the primary balance to debt is sufficient to establish debt sustainability. Second, a structural approach based on a two-country variant of the workhorse Neoclassical dynamic general equilibrium model with an explicit fiscal sector. The model differs from the standard Neoclassical setup in that it introduces endogenous capacity utilization and a limited tax allowance for depreciation expenses in order to match the observed elasticity of the capital tax base to changes in capital taxes. In this setup, the initial debt that is sustainable is the one determined by the present value of primary balances evaluated using equilibrium allocations and prices.

Applications of these first two approaches to cross-country data produced key insights. With the empirical approach, we found in tests based on historical U.S. data and cross-country panels that the sufficiency codition for public debt to be sustainable (the positive, conditional response of the primary balance to debt), cannot be rejected. We also found, however, clear evidence showing that the fiscal dynamics observed in the aftemath of the recent surge in debt in advanced economies represent a significant structural break in the estimated reaction functions. Primary deficits have been too large, and are projected to remain too large, relative to what the fiscal reaction functions predict, and they are also large compared with those observed in the aftermath previous episodes of large surges in debt.

The structural approach differs from the empirical approach in that it can be used to evaluate the positive and normative effects of alternative paths of fiscal adjustment to attain debt sustainability, whereas the empirical approach is silent about these effects. We calibrated the model to U.S. and European data and used it to quantify the effects of unilateral changes in capital and labor taxes, particularly their effects on sustainable debt. The results suggest key differences across Europe and the United States. For the United States, the results suggest that changes in capital taxes cannot make the observed increase in debt sustainable, while small increases in labor taxes could. For Europe, the model predicts that the capacity to use taxes to make higher debt ratios sustainable is nearly fully exhausted. Capital taxation is highly inefficient (in the decreasing segment of dynamic Laffer curves), so cuts in capital taxes would be needed to restore fiscal solvency. Labor taxes are near the peak of the dynamic Laffer curve, and even if increased to the maximum point they do not generate enough revenue to make the present value of the primary balance match the observed surge in debt. In addition, international externalities of capital income taxes were quantitatively large, which suggest that incentives for strategic interaction are non-trivial and could lead to a classic race-to-the-bottom in capital income taxation.

The results of the applications of the empirical and structural approaches paint a bleak picture of the prospects for fiscal adjustment in advanced economies to restore fiscal solvency and make the post-2008 surge in public debt ratios sustainable. In light of these findings, and with the ongoing turbulence in European sovereign debt markets and recurrent debt ceiling debates in the United States, we examined a third approach to debt sustainability that relaxes the assumption of a government committed to repay and allows for the risk of default on domestic public debt. In this environmnet, debt is sustainable when it is part of the equilibrium that includes the optimal debt issuance and default choices of the government. The government has incentives to default as a vehicle for redistribution across agents who are heterogeneous in wealth. Public debt is not sustainable in the absence of default costs or a political bias to weigh the welfare of bond holders by more than their share of the wealth distribution. This is the case because without these assumptions default is always the optimal choice that maximizes the social welfare function of a government who values the utility of all agents, and this is the case regardless of the present value of primary balances used to characterize sustainable debt under the other two approaches.

Quantitatively, this domestic default approach adds valuable insights to those obtained from the empirical and structural approaches without default risk. In particular, sustainable debt falls sharply once risk of default is present, even when it is very small, and it also falls sharply with wealth inequality, because of the strengthened incentive to use default as a tool for redistribution. Hence, estimates of sustainable debt based on models in which the government is assumed to be committed to repay are too optimistic. Moreover, the representative-agent assumption is also likely to lead to optimistic estimates of sustainable debt, because models in this class abstract from the strong incentives to use debt default as a tool for redistribution across heterogeneous agents. A second important insight from the domestic default approach is that sustainable debt is higher if the government's payoff function weighs the welfare of bond hoders more heavily than their share of the wealth distribution. In addition, it is possible that low-wealth agents may also prefer that the government weights high-wealth agents more heavily, instead of acting as a utilitarian government, because higher debt stocks help relax their liquidity constraints.

The three approaches reviewed in this Chapter provide useful tools for conducting debt sustainability analysis. When applied to the current fiscal situation of advanced economies, all three suggest that substantial fiscal adjustment is still needed, is likely to entail substantial welfare costs, and is likely to continue to be challenged by potential default risk in domestic sovereign debt markets.

References

Afonso, Antonio, 2005. "Fiscal Sustainability: The Unpleasant European Case." *FinanzArchiv: Public Finance Analysis*, 61(1): 19–, URL http://ideas.repec.org/a/mhr/finarc/urnsici0015-2218(200503)611_19fstuec_2.0.tx_2-r.html.

Aghion, P. and P. Bolton, 1990. "Government Domestic Debt and the Risk of Default: A Political-Economic Model of the Strategic Role of Debt." *In Public Debt Management: Theory and History, edited by Rudiger Dornbusch and Mario Draghi. New York: Cambridge University Press*: 3151744.

Aguiar, M. and M. Amador, 2013. "Fiscal Policy in Debt Constrained Economies." *NBER Working Papers 17457*.

Aguiar, M. and M. Amador, 2014. "Sovereign Debt." *Handbook of International Economics*, 4: 647–87.

Aguiar, M. and G. Gopinath, 2006. "Defaultable debt, interest rates and the current account." *Journal of International Economics*, 69(1): 64–83.

Aguiar, M., M. Amador, E. Farhi, and G. Gopinath, 2013. "Crisis and Commitment: Inflation Credibility and the Vulnerability to Sovereign Debt Crises." *NBER Working Papers 19516*.

Aiyagari, R. and E. McGrattan, 1998. "The optimum quantity of debt." *Journal of Monetary Economics*, 42: 447–469.

Aiyagari, R., A. Marcet, T. Sargent, and J. Seppala, 2002. "Optimal Taxation without State-Contingent Debt." *Journal of Political Economy*, 110(6): 1220–1254.

Alesina, A. and G. Tabellini, 1990. "A Positive Theory of Fiscal Deficits and Government Debt." *The Review of Economic Studies*, 57: 403–414.

Alesina, Alberto and Guido Tabellini, 2005. "Why is Fiscal Policy Often Procyclical?" Working Paper 11600, National Bureau of Economic Research, URL http://www.nber.org/papers/w11600.

Amador, M., 2003. "A Political Economy Model of Sovereign Debt Repayment." *Stanford University mimeo*.

Andreasen, E., G. Sandleris, and A. Van der Ghote, 2011. "The Political Economy of Sovereign Defaults." *Universidad Torcuato Di Tella, Business School Working Paper*.

Arellano, C., 2008. "Default Risk and Income Fluctuations in Emerging Economies." *American Economic Review*, 98(3): 690–712.

Azzimonti, M., E. de Francisco, and V. Quadrini, 2014. "Financial Globalization, Inequality, and the Rising Public Debt." *American Economic Review*, 104(8): 2267–2302.

Barro, R., 1979. "On the determination of the public debt." *Journal of Political Economy*, 87(5): 940–971.

Basu, S., 2009. "Sovereign debt and domestic economic fragility." *Manuscript, Massachusetts Institute of Technology*.

Blanchard, Oliver J., Jean-Claude Chouraqui, Robert P. Hagemann, and Nichola Sartor, 1990. "The Sustainability of Fiscal Policy: New Answers to an Old Question." *OECD Economic Studies*, 15(2): 7–36.

Blanchard, Olivier J., 1990. "Suggestions for a New Set of Fiscal Indicators." OECD Economics Department Working Papers 79, OECD Publishing, URL http://ideas.repec.org/p/oec/ecoaaa/79-en.html.

Bocola, L., 2014. "The Pass-Through of Sovereign Risk." *Manuscript, University of Pennsylvania*.

Bohn, Henning, 1995. "The Sustainability of Budget Deficits in a Stochastic Economy." *Journal of Money, Credit and Banking*, 27(1): 257–71, URL http://ideas.repec.org/a/mcb/jmoncb/v27y1995i1p257-71.html.

Bohn, Henning, 1998. "The Behavior Of U.S. Public Debt And Deficits." *The Quarterly Journal of Economics*, 113(3): 949–963, URL http://ideas.repec.org/a/tpr/qjecon/v113y1998i3p949-963.html.

Bohn, Henning, 2007. "Are stationarity and cointegration restrictions really necessary for the intertemporal budget constraint?" *Journal of Monetary Economics*, 54(7): 1837–1847, URL http://ideas.repec.org/a/eee/moneco/v54y2007i7p1837-1847.html.

Bohn, Henning, 2008. "The Sustainability of Fiscal Policy in the United States." In Reinhard Neck and Jan-Egbert Sturm, eds., "Sustainability of public debt," Cambridge, Mass.: MIT Press.

Boz, E., P. D'Erasmo, and B. Durdu, 2014. "Sovereign Risk and Bank Balance Sheets: The Role of Macroprudential Policies." *Manuscript*.

Broner, F. and J. Ventura, 2011. "Globalization and Risk Sharing." *Review of Economic Studies*, 78(1): 49–82.

Broner, F., A. Martin, and J. Ventura, 2010. "Sovereign Risk and Secondary Markets." *American Economic Review*, 100(4): 1523–55.

Brutti, 2011. "Sovereign defaults and liquidity crises." *Journal of International Economics*, 84 (1): 651772.

Buiter, Willem H, 1985. "A guide to public sector debt and deficits." *Economic policy*, 1(1): 13–61.

Calvo, G., 1988. "Servicing the Public Debt: The Role of Expectations." *American Economic Review*, 78(4): 647–61.

Carey, David and Harry Tchilinguirian, 2000. "Average Effective Tax Rates on Capital, Labour and Consumption." *OECD Economics Department Working Papers: 258*.

Chalk, Nigel Andrew and Richard Hemming, 2000. *Assessing fiscal sustainability in theory and practice*. International Monetary Fund.

Chari, V. V., Lawrence J. Christiano, and Patrick J. Kehoe, 1994. "Optimal Fiscal Policy in a Business Cycle Model." *Journal of Political Economy*, 102(4): 617–652.

Cooley, Thomas F and Gary D Hansen, 1992. "Tax distortions in a neoclassical monetary economy." *Journal of Economic Theory*, 58(2): 290 – 316, URL http://www.sciencedirect.com/science/article/pii/002205319290056N.

Cuadra, G., Sanchez J., and Sapriza H., 2010. "Fiscal Policy and Default Risk in Emerging Markets." *Review of Economic Dynamics*, 13(2): 452–469.

D'Erasmo, P., 2011. "Government Reputation and Debt Repayment in Emerging Economies." *mimeo*.

D'Erasmo, P. and E. Mendoza, 2013. "Distributional incentives in an equilibrium model of domestic sovereign default." *National Bureau of Economic Research, No. w19477*.

D'Erasmo, P. and E. Mendoza, 2014. "Optimal Domestic Sovereign Default." *Manuscript, University of Pennsylvania*.

Di Casola, P. and S. Sichlimiris, 2014. "Domestic and External Sovereign Debt." *Working Paper, Stockholm School of Economics*.

Dias, D., C. Richmond, and M. Wright, 2012. "In for a Penny, In for a 100 Billion Pounds: Quantifying the Welfare Benefits from Debt Relief." *mimeo*.

Dixit, A. and J. Londregan, 2000. "Political Power and the Credibility of Government Debt." *Journal of Economic Theory*, 94: 8017105.

Dovis, A., M. Golosov, and A. Shourideh, 2014. "Sovereign Debt vs Redistributive Taxes: Financing Recoveries in Unequal and Uncommitted Economies." *mimeo*.

Durdu, Bora C., Enrique G. Mendoza, and Marco E. Terrones, 2013. "On the Solvency of Nations: Cross-Country Evidence on the Dynamics of External Adjustment." *Journal of Monetary Economics*, 32: 762–780.

Dwenger, Nadja and Viktor Steiner, 2012. "Profit Taxation and the Elasticity of the Corporate Income Tax Base: Evidence from German Corporate Tax Return Data." *National Tax Journal*, 65(1): 117–150.

Eaton, J. and M. Gersovitz, 1981. "Debt with Potential Repudiation: Theoretical and Empirical Analysis." *Review of Economic Studies*, 48(2): 289–309.

Escolano, Mr Julio, 2010. *A practical guide to public debt dynamics, fiscal sustainability, and cyclical adjustment of budgetary aggregates*. International Monetary Fund.

Ferriere, 2014. "Sovereign Default, Inequality, and Progressive Taxation." *mimeo*.

Floden, M., 2001. "The effectiveness of government debt and transfers as insurance." *Journal of Monetary Economics*, 48: 81–108.

Gali, Jordi, 1991. "Budget Constraints and Time-Series Evidence on Consumption." *American Economic Review*, 81(5): 1238–53, URL http://ideas.repec.org/a/aea/aecrev/v81y1991i5p1238-53.html.

Gennaioli, N., A. Martin, and S. Rossi, 2014. "Sovereign default, domestic banks and financial institutions." *Journal of Finance*.

Ghosh, Atish R., Jun I. Kim, Enrique G. Mendoza, Jonathan D. Ostry, and Mahvash S. Qureshi, 2013a. "Fiscal Fatigue, Fiscal Space and Debt Sustainability in Advanced Economies." *Economic Journal*, 0: F4–F30, URL http://ideas.repec.org/a/ecj/econjl/vy2013ipf4-f30.html.

Ghosh, Atish R., Jun I. Kim, Enrique G. Mendoza, Jonathan D. Ostry, and Mahvash S. Qureshi, 2013b. "Fiscal Fatigue, Fiscal Space and Debt Sustainability in Advanced Economies." *The Economic Journal*, 123: F4–F30.

Golosov, M. and T. Sargent, 2012. "Taxation, redistribution, and debt with aggregate shocks." *working paper Princeton University*.

Greenwood, Jeremy and Gregory W. Huffman, 1991. "Tax Analysis in a Real-Business-Cycle Model." *Journal of Monetary Economics*, 22(2): 167–190.

Gruber, Jonathan and Joshua Rauh, 2007. "How Elastic Is the Corporate Income Tax Base?" In "Taxing Corporate Income in the 21st Century," Cambridge University Press.

Guembel, A. and O. Sussman, 2009. "Sovereign Debt without Default Penalties." *Review of Economic Studies*, 76: 1297–1320.

Hamilton, James D and Marjorie A Flavin, 1986. "On the Limitations of Government Borrowing: A Framework for EmpiricalTesting." *American Economic Review*, 76(4): 808–19, URL http://ideas.repec.org/a/aea/aecrev/v76y1986i4p808-19.html.

Hansen, Lars Peter, William Roberds, and Thomas J Sargent, 1991. "Time series implications of present value budget balance and of martingale models of consumption and taxes." In Lars Peter Hansen, Thomas J Sargent, John Heaton, Albert Marcet, and William Roberds, eds., "Rational expectations econometrics," Boulder, CO: Westview Press, 121–61.

Hatchondo, J.C., L. Martinez, and H. Sapriza, 2009. "Heterogeneous Borrowers in Quantitative Models of Sovereign Default." *International Economic Review*, 50: 1291751.

Heathcote, J., 2005. "Fiscal Policy with Heterogeneous Agents." *Review of Economic Studies*, 72: 161–188.

House, Christopher L. and Matthew D. Shapiro, 2008. "Temporary Investment Tax Incentives: Theory with Evidence from Bonus Depreciation." *American Economic Review*, 98(3): 737–68, URL http://www.aeaweb.org/articles.php?doi=10.1257/aer.98.3.737.

IMF, International Monetary Fund, 2003. "World Economic Outlook." IMF Occasional Papers 21, International Monetary Fund.

Jeon, K. and Z. Kabukcuoglu, 2014. "Income Inequality and Sovereign Default." *working paper, University of Pittsburgh*.

Kaminsky, Graciela L., Carmen M. Reinhart, and Carlos A. Vegh, 2005. "When It Rains, It Pours: Procyclical Capital Flows and Macroeconomic Policies." In "NBER Macroeconomics Annual 2004, Volume 19," NBER Chapters, National Bureau of Economic Research, Inc, 11–82, URL http://ideas.repec.org/h/nbr/nberch/6668.html.

King, Robert G., Charles I. Plosser, and Sergio T. Rebelo, 1988. "Production, Growth and Business Cycles: I. The Basic Neoclassical Model." *Journal of Monetary Economics*, 21(2): 195–232.

Ljungqvist, Lars and Thomas J Sargent, 2012. *Recursive Macroeconomic Theory, 3rd ed*. The MIT Press, 1360p.

Lorenzoni, G. and I. Werning, 2013. "Slow moving debt crises." *NBER Working Paper No. w19228*.

Lucas, Robert E., 1990. "Why Doesn't Capital Flow from Rich to Poor Countries?" *American Economic Review, Papers and Proceedings of the Hundred and Second Annual Meeting of the American Economic Association*, 80(2): 92–96.

Mendoza, E.G. and V.Z. Yue, 2012. "A General Equilibrium Model of Sovereign Default and Business Cycles." *Quarterly Journal of Economics*, 127(2): 889–946.

Mendoza, Enrique G. and Jonathan D. Ostry, 2008a. "International Evidence on Fiscal Solvency: Is Fiscal Policy Responsible." *Journal of Monetary Economics*, 55: 1081–1093.

Mendoza, Enrique G. and Jonathan D. Ostry, 2008b. "International evidence on fiscal solvency: Is fiscal policy responsible17?" *Journal of Monetary Economics*, 55(6): 1081 – 1093, URL http://www.sciencedirect.com/science/article/pii/S0304393208000779.

Mendoza, Enrique G. and P. Marcelo Oviedo, 2006. "Fiscal Policy and Macroeconomic Uncertainty in Emerging Markets: The Tale of the Tormented Insurer." 2006 Meeting Papers 377, Society for Economic Dynamics, URL http://ideas.repec.org/p/red/sed006/377.html.

Mendoza, Enrique G. and P. Marcelo Oviedo, 2009. "Public Debt, Fiscal Solvency and Macroeconomic Uncertainty in Latin America The Cases of Brazil, Colombia, Costa Rica and Mexico." *Economa Mexicana NUEVA POCA*, 0(2): 133–173, URL http://ideas.repec.org/a/emc/ecomex/v18y2009i2p133-173.html.

Mendoza, Enrique G. and Linda L. Tesar, 1998. "The International Ramifications of Tax Reforms: Supply-Side Economics in a Global Economy." *American Economic Review*, 88(1): 226–245.

Mendoza, Enrique G. and Linda L. Tesar, 2005. "Why Hasn't Tax Competition Triggered a Race to the Bottom? Some Quantitative Lessons from the EU." *Journal of Monetary Economics*, 52(1): 163–204.

Mendoza, Enrique G., Assaf Razin, and Linda L. Tesar, 1994. "Effective Tax Rates in Macroeconomics: Cross-Country Estimates of Tax Rates on Factor Incomes and Consumption." *Journal of Monetary Economics*, 34(3): 297–323.

Mendoza, Enrique G., Gian Maria Milesi-Ferretti, and Patrick Asea, 1997. "On the Ineffectiveness of Tax Policy in Altering Long-Run Growth: Harberger's Superneutrality Conjecture." *Journal of Public Economics*, 66(2): 99–126.

Mendoza, Enrique G., Linda L. Tesar, and Jing Zhang, 2014. "Saving Europe?: The Unpleasant Arithmetic of Fiscal Austerity in Integrated Economies." *University of Michigan Working Paper*.

Mengus, E., 2014. "Honoring Sovereign Debt or Bailing Out Domestic Residents? A Theory of Internal Cost of Default." *WP Banque de France 480*.

Neck, Reinhard and Jan-Egbert Sturm, 2008. *Sustainability of public debt*. Mit Press.

Panizza, U., F. Sturzenegger, and J. Zettelmeyer, 2009. "The Economics and Law of Sovereign Debt and Default." *Journal of Economic Literature*, 47(3): 651–98.

Perez, D., 2015. "Sovereign Debt, Domestic Banks and the Provision of Public Liquidity." *Manuscript*.

Pitchford and Wright, 2012. "Holdouts in Sovereign Debt Restructuring: A Theory of Negotiation in a Weak Contractual Environment." *Review of Economic Studies*, 79(2): 812–837.

Pouzo, D. and I. Presno, 2014. "Optimal Taxation with Endogenous Default under Incomplete Markets." *U.C. Berkeley, mimeo*.

Prescott, Edward C., 2004. "Why Do Americans Work So Much More Than Europeans." *Federal Reserve Bank of Minneapolis Quarterly Review*, July.

Quintos, Carmela E, 1995. "Sustainability of the Deficit Process with Structural Shifts." *Journal of Business & Economic Statistics*, 13(4): 409–17, URL http://ideas.repec.org/a/bes/jnlbes/v13y1995i4p409-17.html.

Reinhart, Carmen M. and Kenneth S. Rogoff, 2011. "The Forgotten History of Domestic Debt." *The Economic Journal*, 121(552): 319–350, URL http://dx.doi.org/10.1111/j.1468-0297.2011.02426.x.

Sorensen, Peter B., 2001. "Tax Coordination and the European Union: What Are the Issues?" *University of Copenhagen Working Paper*.

Sosa-Padilla, C., 2012. "Sovereign Defaults and Banking Crises." *Manuscript*.

Tabellini, G., 1991. "The Politics of Intergenerational Redistribution." *Journal of Political Economy*, 99: 3351757.

Talvi, Ernesto and Carlos A. Vegh, 2005. "Tax base variability and procyclical fiscal policy in developing countries." *Journal of Development Economics*, 78(1): 156–190, URL http://ideas.repec.org/a/eee/deveco/v78y2005i1p156-190.html.

Tauchen, G., 1986. "Finite state Markov-chain approximation to univariate and vector autoregressions." *Economics Letters*, 20: 177–81.

Tomz and Wright, 2012. "Empirical research on sovereign debt and default." *Working Paper Series WP-2012-06, Federal Reserve Bank of Chicago*.

Trabandt, Mathias and Harald Uhlig, 2011. "The Laffer Curve Revisited." *Journal of Monetary Economics*, 58(4): 305–327.

Trabandt, Mathias and Harald Uhlig, 2012. "How do Laffer Curves Differ Across Countries?" *BFI Paper no. 2012-001.*

Trehan, Bharat and Carl Walsh, 1988. "Common trends, the government's budget constraint, and revenue smoothing." *Journal of Economic Dynamics and Control*, 12(2-3): 425–444, URL http://EconPapers.repec.org/RePEc:eee:dyncon:v:12:y:1988:i:2-3:p:425-444.

Vasishtha, 2010. "Domestic versus external borrowing and fiscal policy in emerging markets." *Review of International Economics*, 18(5): 1058–1074.

Yue, V., 2010. "Sovereign Default and Debt Renegotiation." *Journal of International Economics*, 80 (2): 176–187.

Appendices

Appendix

A. Details on Measurement of Effective Tax Rates

Effective tax rates have been widely used in a number of studies including Carey and Tchilinguirian (2000), Sorensen (2001) and recently by Trabandt and Uhlig (2011, 2012). The MRT methodology uses the wedge between reported pre-tax and post-tax macro estimates of consumption, labor income and capital income to estimate the effective tax rate levied on each of the three tax bases. This methodology has two main advantages. First, it provides a fairly simple approach to estimating effective tax rates at the macro level using readily available data, despite the complexity of the various credits and deductions of national tax codes. Second, these tax rates correspond directly to the tax rates in a wide class of representative-agent models with taxes on consumption and factor incomes, including the model proposed here. The main drawback of the MRT tax rates is that they are average, not marginal, tax rates, but because they are intended for use in representative-agent models, this disadvantage is less severe than it would be in a model with heterogeneous agents. Moreover Mendoza, Razin, and Tesar (1994) show that existing estimates of aggregate marginal tax rates have a high time-series correlation with the MRT effective tax rates, and that both have similar cross-country rankings.

Following Trabandt and Uhlig (2011), we modify the MRT estimates of labor and capital taxes by adding supplemental wages (i.e. employers' contributions to social security and private pension plans) to the tax base for personal income taxes. These data were not available at the time of the MRT 1994 calxculations and, because this adjustment affects the calculation of the personal income tax rate, which is an initial step for the calculation of labor and capital income tax rates, it alters the estimates of both. In general, this adjustment makes the labor tax base bigger and therefore the labor tax rate smaller than the MRT original estimates.[46]

B. Transition Dynamics under a Unilateral Increase in τ_K

The transitional dynamics of key macro variables are presented in the left panel of Figure A.1 and discussed in Section 3.3.1. Here we focus on fiscal variables plotted in the right panel of Figure A.1. In the U.S., tax revenue from capital income increases almost immediately to a higher constant level when τ_k rises, while the revenues from labor and consumption taxes decline both on impact and in the long run. Labor and consumption tax rates are not changing, but both tax bases fall on impact and then decline monotonically to their new, lower steady states. The primary fiscal balance and total revenue both rise initially but then converge to about the same levels as in the pre-crisis stationary equilibrium. For the primary balance, this pattern is implied by the pattern of the total revenue, since government expenditures and entitlements are held constant. For total revenue, the transitional increase indicates that the rise in capital tax revenue more than offsets the decline in the revenue from the other taxes in the transition, while in the long-run they almost offset each other exactly. This is possible because the change in τ_K to 0.4 is on the increasing side

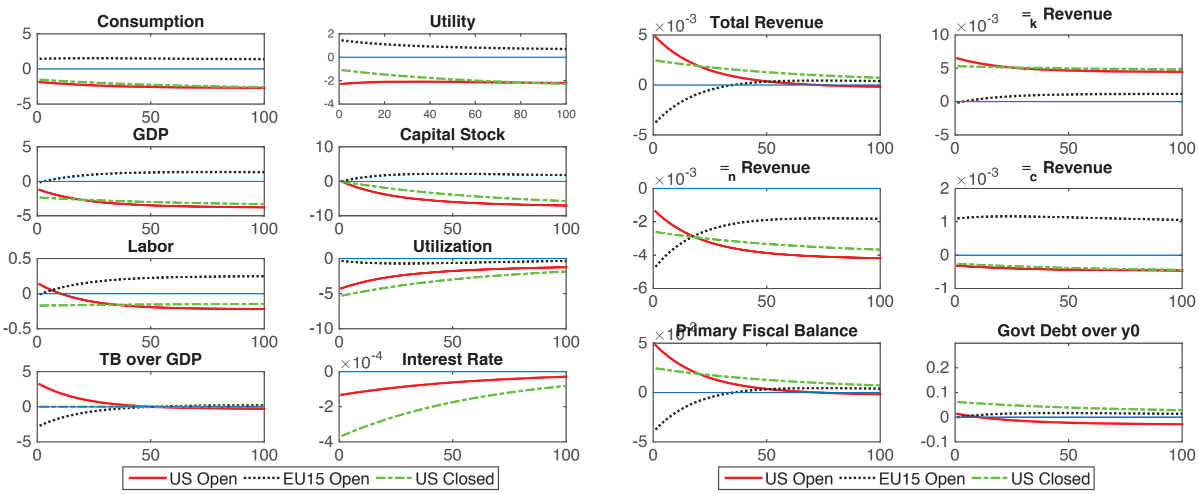
[46] Trabandt and Uhlig make a further adjustment to the MRT formulae by attributing some of the operating surplus of corporations and non-incorporated private enterprises to labor, with the argument that this represents a return to entrepreneurs rather than to capital. We do not make this modification because the data do not provide enough information to determine what fraction of the operating surplus should be allocated to labor.

of the Laffer curve, and in fact it is the maximum point of the curve. Hence, this capital tax hike does not reduce capital tax revenues.

The public debt dynamics in the bottom-right panel of Figure A.1 shows that on impact, government debt in the U.S. responds to the 40 percent tax rate by increasing 5 percentage points, reflecting the extra initial debt that can be supported at the higher capital tax rate. Since the primary fiscal balance rises on impact and then declines monotonically, the debt ratio also falls monotonically during the transition, and converges to a ratio that is actually about 4 percentage points below the pre-crisis level. Hence, the debt shock is completely undone by the capital tax hike in the long-run. If the U.S. implements the same tax hike under autarky, it generates significantly larger revenues and primary balances, and hence the debt ratio increases more initially and converges to a higher steady state of 1 percentage points above the pre-crisis level. This is again a reflection of the cross-country externalities faced by the U.S. as an open economy, since equally-sized tax hikes produce significantly higher revenues under autarky.

The cross-country externalities are also reflected in the fiscal dynamics of the EU15 shown in Figure A.1. Maintaining revenue neutrality (in present value) still allows both its revenue and primary balance to fall initially, while in the long run both converge to very similar levels as in the pre-crisis steady state. Removing the labor tax adjustment in the EU15 that maintains revenue neutrality, the present value of its primary balance as a share of GDP would increase by 10.1 percentage points relative to the pre-crisis ratio, and both its revenue and primary balances would be higher than in the plots shown in Figure A.1. The welfare gain, however, would be negligible instead of 0.74 percent in lifetime consumption.

Figure A.1: Responses to a US Capital Tax Rate Increase



(a) Macro Variables (b) Fiscal Variables

Table 1: FISCAL REACTION FUNCTION OF THE UNITED STATES: 1792-2014

Model: Coefficient	Base model (1)	Asymmetric response (2)	AR(1) term (3)	Debt Squared (4)	Time trend (5)	Bohn's Sample (1793-2003) (6)	Pre-Recession (1793-2008) (7)
Constant	0.00648 (0.004)	0.00540 (0.003)*	0.00974 (0.008)	0.00653 (0.004)	0.00601 (0.006)	0.00485 (0.003)*	0.00470 (0.003)
Initial debt d_t^*	0.07779 (0.040)*	0.08689 (0.030)***	0.10477 (0.032)***	0.07715 (0.038)*	0.07674 (0.035)**	0.10498 (0.023)***	0.10188 (0.022)***
GDP gap	0.07404 (0.078)	0.07300 (0.079)	0.15330 (0.043)***	0.07390 (0.079)	0.07490 (0.077)	0.07987 (0.086)	0.07407 (0.086)
Military Expenditure	-0.72302 (0.133)***	-0.72001 (0.136)***	-0.98955 (0.110)***	-0.72320 (0.133)***	-0.72462 (0.135)***	-0.77835 (0.135)***	-0.76857 (0.135)***
$\max(0, d_t^* - \bar{d})$		-0.14487 (0.061)					
AR(1)			0.89154 (0.029)***				
$(d_t^* - \bar{d})^2$				0.00261 (0.044)			
Time trend					6.89E-06 (5.9E-05)		
s.e	0.0239	0.0240	0.198	0.0120	0.0240	0.0210	0.0209
Adj. R-squared:	0.606	0.605	0.901	0.614	0.605	0.695	0688
Observations:	223	223	222	223	223	213	217

Note: HAC standard errors shown in parenthesis, 2-lag window prewhitening. "*","**", "***" denote that the corresponding coefficient is statistically significant at the 90, 95 and 99 percent confidence levels. Output gap is percent deviation from Hodrick-Prescott trend. Military expenditure includes all Department of Defense and Department of Veterans Affairs outlays.

Table 2: FISCAL REACTION FUNCTIONS OF ADVANCED ECONOMIES (1951-2013)

	All Advanced Economies					
Model	(1)	(2)	(3)	(4)	(5)	(6)
Constant	11.23917 (3.134)***	1.76019 (0.037)***	-1.02696 (0.472)**	-0.07294 (0.195)	-1.42979 (2.651)	0.02521 (0.222)
Previous debt d_{t-1}	0.06916 (0.013)***	0.01461 (0.001)***	0.01983 (0.010)**	0.00295 (0.005)	0.02750 (0.010)***	-0.00076 (0.005)
GDP gap	0.17053 (0.050)***	0.28046 (0.058)***	0.31501 (0.065)***	0.34696 (0.060)***	0.34939 (0.073)***	0.40503 (0.073)***
Government Expenditure	-0.35654 (0.078)***	-0.06305 (0.013)***				
Government Expenditure Gap			-0.10449 (0.031)***	-0.12511 (0.031)***		
Govt Consumption Gap (Nat. Acc.)					-0.20579 (0.064)***	-0.33638 (0.070)***
Country AR(1)	Yes	No	Yes	No	Yes	No
s.e.	1.603	2.814	1.709	2.813	1.796	2.884
Adj R-squared:	0.766	0.277	0.755	0.306	0.733	0.304
Observations:	1285	1346	1218	1273	1139	1186
Countries:	25	25	25	25	25	25

Note: All regressions include country fixed effect and White cross-section correcter standard errors and covariances. Standard errors shown in parenthesis. "*","**", "***" denote that the corresponding coefficient is statistically significant at the 90, 95 and 99 percent confidence levels. Output, government expenditure and government consumption gaps are percent deviation from Hodrick-Prescott trend.

Table 3: FISCAL REACTION FUNCTIONS OF EMERGING ECONOMIES (1951-2013)

Model	(1)	(2)	(3)	(4)	(5)	(6)
Constant	9.99549 (1.473)***	1.32486 (0.409)***	-2.38214 (0.462)***	-1.88325 (0.284)***	-2.33727 (0.544)***	-1.70461 (0.322)***
Previous Debt d_{t-1}	0.03806 (0.009)***	0.05657 (0.006)***	0.05452 (0.006)***	0.04519 (0.005)***	0.05280 (0.008)***	0.04376 (0.006)***
GDP gap	0.03698 (0.029)	0.07352 (0.027)***	0.15962 (0.034)***	0.15509 (0.027)***	0.07568 (0.042)*	0.06831 (0.030)**
Government Expenditure	-0.44322 (0.049)***	-0.15638 (0.020)***				
Government Expenditure Gap			-0.11986 (0.012)***	-0.12420 (0.012)***		
Govt Consumption Gap (Nat. Acc.)					-0.01302 (0.018)	-0.02662 (0.014)*
Country AR(1)	Yes	No	Yes	No	Yes	No
s.e.	1.854	2.630	1.772	2.450	2.072	2.795
Adj R-squared:	0.666	0.346	0.698	0.437	0.589	0.321
Observations:	1071	1144	977	1035	967	1022
Countries:	33	33	33	33	33	33

Note: All regressions include country fixed effect and White cross-section correcter standard errors and covariances. Standard errors shown in parenthesis. "*","**", "***" denote that the corresponding coefficient is statistically significant at the 90, 95 and 99 percent confidence levels. Output, government expenditure and government consumption gaps are percent deviation from Hodrick-Prescott trend.

Table 4: FISCAL REACTION FUNCTIONS FOR ADVANCED AND EMERGING ECONOMIES (1951-2013)

Model	(1)	(2)	(3)	(4)	(5)	(6)
Constant	10.53960	1.50777	-2.23188	-0.65482	-2.29040	-0.57649
	(1.528)***	(0.357)***	(0.400)***	(0.160)***	(0.466)***	(0.172)***
Previous Debt	0.05138	0.02962	0.04576	0.01634	0.04661	0.01500
d_{t-1}	(0.007)***	(0.004)***	(0.006)***	(0.004)***	(0.006)***	(0.004)***
GDP gap	0.07864	0.12611	0.20956	0.20590	0.16205	0.15198
	(0.031)**	(0.030)***	(0.043)***	(0.032)***	(0.051)***	(0.036)***
Government	-0.40043	-0.08823				
Expenditure	(0.047)***	(0.015)***				
Government			-0.11558	-0.12788		
Expenditure Gap			(0.014)***	(0.016)***		
Govt. Consumption					-0.03764	-0.07534
Gap (Nat. Acc.)					(0.021)*	(0.020)***
Country AR(1)	Yes	No	Yes	No	Yes	No
s.e.	1.729	2.796	1.756	2.727	1.970	2.915
Adj R-squared:	0.720	0.275	0.718	0.328	0.656	0.254
Observations:	2356	2490	2195	2308	2106	2208
Countries:	58	58	58	58	58	58

Note: All regressions include country fixed effect and White cross-section correcter standard errors and covariances. Standard errors shown in parenthesis. "*","**", "***" denote that the corresponding coefficient is statistically significant at the 90, 95 and 99 percent confidence levels. Output, government expenditure and government consumption gaps are percent deviation from Hodrick-Prescott trend.

Table 5: MACROECONOMIC STANCE AS OF 2008

	EU15											GDP-weighted ave.		
	AUT	BEL	DEU	ESP	FRA	GBR	ITA	NLD	POL	SWE	Other	EU15	US	All
(a) Macro Aggregates														
τ_C	0.19	0.17	0.17	0.12	0.17	0.14	0.13	0.20	0.21	0.26	0.23	0.17	0.04	0.11
τ_L	0.51	0.47	0.41	0.35	0.45	0.30	0.48	0.47	0.38	0.55	0.39	0.41	0.27	0.35
τ_K	0.25	0.45	0.24	0.25	0.38	0.40	0.38	0.26	0.16	0.37	0.31	0.32	0.37	0.34
c/y	0.53	0.52	0.56	0.57	0.57	0.64	0.59	0.45	0.62	0.47	0.58	0.57	0.68	0.62
x/y	0.22	0.24	0.19	0.29	0.22	0.17	0.21	0.20	0.24	0.20	0.23	0.21	0.21	0.21
g/y	0.19	0.23	0.18	0.19	0.23	0.22	0.20	0.26	0.19	0.26	0.21	0.21	0.16	0.19
tb/y	0.06	0.01	0.06	−0.06	−0.02	−0.02	−0.01	0.08	−0.04	0.07	−0.02	0.00	−0.05	−0.02
Rev/y	0.48	0.49	0.44	0.37	0.50	0.42	0.46	0.47	0.40	0.54	0.45	0.45	0.32	0.39
Total Exp/y	0.49	0.50	0.44	0.41	0.53	0.47	0.49	0.46	0.43	0.52	0.48	0.47	0.39	0.43
(b) Debt Shocks														
d_{2007}/y_{2007}	0.31	0.73	0.43	0.18	0.36	0.28	0.87	0.28	0.17	−0.23	0.13	0.38	0.43	0.40
d_{2011}/y_{2011}	0.45	0.80	0.51	0.46	0.63	0.62	1.00	0.38	0.32	−0.25	0.45	0.58	0.74	0.65
$\Delta d/y$	0.14	0.07	0.09	0.28	0.27	0.33	0.14	0.10	0.15	−0.02	0.32	0.20	0.31	0.25

Other is a GDP weighted average of Denmark, Finland, Greece, Ireland, and Portugal
Source: OECD Revenue Statistics, OECD National income Accounts, and EuroStat. Tax rates are author's calculations based on Mendoza, Razin, and Tesar (1994). "Total Exp" is total non-interest government outlays.

Table 6: PARAMETER VALUES

		US	EU15	Sources
Preferences:				
β	discount factor	0.998		steady state Euler equation for capital
σ	risk aversion	2.000		standard DSGE value
a	labor supply elasticity	2.675		$\bar{l} = 0.18$ (Prescott, 2004)
Technology:				
α	labor income share	0.61		(Trabandt and Uhlig, 2011)
γ	growth rate	0.0038		real GDP p.c. growth of sample countries (Eurostat 1995–2011)
η	capital adjustment cost	2		Elasticity of capital tax base (Gruber and Rauh, 2007, Dwenger and Steiner, 2012)
$\bar{m}$	capacity utilization	1		steady state normalization
$\delta(\bar{m})$	depreciation rate	0.0163		capital law of motion, $x/y = 0.19$, $k/y = 2.62$ (OECD, AMECO)
χ_0	$\delta(m)$ coefficient	0.023	0.024	optimality condition for utilization given $\delta(\bar{m})$, $\bar{m}$
χ_1	$\delta(m)$ exponent	1.44	1.45	set to yield $\delta(\bar{m}) = 0.0164$
ω	country size	0.46	0.54	GDP share in all sample countries
Fiscal Policy:				
g/y	Gov't exp share in GDP	0.16	0.21	OECD National Income Accounts
τ_C	consumption tax	0.04	0.17	MRT modified
τ_L	labor income tax	0.27	0.41	MRT modified
τ_K	capital income tax	0.37	0.32	MRT modified
θ	depreciation allowance limitation	0.20		$(REV_K^{corp}/REV_K)(K^{NR}/K)$, OECD Revenue Statistics and EU KLEMS

Note: The implied growth adjusted discount factor $\tilde{\beta}$ is 0.995, and the implied pre-crisis annual interest rate is 3.8%. REV_K^{corp}/REV_K is the ratio of corporate tax revenue to total capital tax revenue. K^{NR}/K is the ratio of nonresidential fixed capital to total fixed capital.

Table 7: BALANCED GROWTH ALLOCATIONS (GDP RATIOS) OF 2008

	US		EU15	
	Data	Model	Data	Model
c/y	0.68	0.63	0.57	0.56
i/y	0.21	0.21	0.21	0.23
g/y^*	0.16	0.16	0.21	0.21
tb/y	-0.05	0.00	0.00	0.00
Rev$/y$	0.32	0.32	0.45	0.46
d/y^*	0.76	0.76	0.60	0.60

Table 8: MACROECONOMIC EFFECTS OF AN INCREASE IN US CAPITAL TAX RATE

(The EU15 maintains revenue neutrality with labor tax)

	Open Economy				Closed Economy	
	US		EU15		US	
Tax rates	Old	New	Old	New	Old	New
τ_K	0.37	0.40	0.32	0.32	0.37	0.40
τ_C	0.04	0.04	0.17	0.17	0.04	0.04
τ_L	0.27	0.27	0.41	0.40	0.27	0.27
PV of fiscal deficit over pre-crisis GDP as percentage point change from original ss		1.37		0.00		6.16
Welfare effects (percent)						
Steady-state gain		−2.27		0.59		−2.55
Overal gain		−2.19		0.74		−2.22
Percentage changes	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect
y	−1.23	−3.87	−0.15	1.25	−2.35	−3.57
c	−1.87	−2.83	1.44	1.28	−1.53	−2.91
k	0.00	−7.61	0.00	1.25	0.00	−7.32
Percentage point changes						
tb/y	3.21	−0.30	−2.70	0.24		
i/y	−3.01	−1.02	1.77	0.00	−0.91	−1.02
r	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
l	0.11	−0.17	−0.01	0.21	−0.13	−0.11
m	−4.23	−0.866	−0.315	−0.000	−5.277	−0.866

Table 9: MACROECONOMIC EFFECTS OF A DECREASE IN EU15 CAPITAL TAX RATE

(The U.S maintains revenue neutrality with labor tax)

	Open Economy				Closed Economy	
	US		EU15		EU15	
Tax rates	Old	New	Old	New	Old	New
τ_K	0.37	0.37	0.32	0.20	0.37	0.37
τ_C	0.04	0.04	0.17	0.17	0.04	0.17
τ_L	0.27	0.28	0.41	0.41	0.27	0.41
PV of fiscal deficit over pre-crisis GDP as percentage point change from original ss		-0.00		22.34		9.62
Welfare effects (percent)						
Steady-state gain		0.36		7.35		7.93
Overal gain		−0.23		6.86		6.99
Percentage changes	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect
y	2.30	−1.40	6.05	12.77	8.38	11.99
c	−1.59	−0.64	5.82	9.03	5.14	9.19
k	0.00	−1.50	0.00	26.10	0.00	25.23
Percentage point changes						
tb/y	8.92	−0.75	−6.57	0.56		
i/y	−5.64	0.00	8.18	3.66	3.31	3.66
r	0.00	−0.00	0.00	−0.00	0.00	−0.00
l	0.47	−0.31	0.05	0.48	0.43	0.36
m	2.34	0.00	12.93	3.31	14.94	3.31

Table 10: MACROECONOMIC EFFECTS OF AN INCREASE IN THE U.S. LABOR TAX RATE

	(The EU15 maintains revenue neutrality with labor tax)					
	US		EU15		US	
Tax rates	Old	New	Old	New	Old	New
τ_K	0.37	0.37	0.32	0.32	0.37	0.37
τ_C	0.04	0.04	0.17	0.17	0.04	0.04
τ_L	0.27	0.29	0.41	0.41	0.27	0.29
PV of fiscal deficit over pre-crisis GDP as percentage point change from original ss		31.00		0.00		31.95
Welfare effects (percent)						
Steady-state gain		−0.92		0.15		−0.98
Overal gain		−0.90		0.18		−0.91
Percentage changes	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect
y	−1.16	−1.75	−0.02	0.30	−1.41	−1.68
c	−1.88	−2.09	0.34	0.31	−1.80	−2.10
k	0.00	−1.75	0.00	0.30	0.00	−1.68
Percentage point changes						
tb/y	0.72	−0.07	−0.61	0.06		
i/y	−0.46	0.00	0.40	0.00	0.02	−0.00
r	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
l	−0.29	−0.35	0.00	0.05	−0.35	−0.34
m	−0.73	0.00	−0.06	−0.00	−0.96	0.00

Table 11: MACROECONOMIC EFFECTS OF AN INCREASE IN THE EU15 LABOR TAX RATE

	(The U.S. maintains revenue neutrality with labor tax)					
	US		EU15		EU15	
Tax rates	Old	New	Old	New	Old	New
τ_K	0.37	0.37	0.32	0.32	0.37	0.37
τ_C	0.04	0.04	0.17	0.17	0.04	0.17
τ_L	0.27	0.27	0.41	0.47	0.27	0.47
PV of fiscal deficit over pre-crisis GDP as percentage point change from original ss		0.00		11.75		16.02
Welfare effects (percent)						
Steady-state gain		−0.12		−5.04		−5.19
Overal gain		0.07		−4.91		−4.92
Percentage changes	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect	Impact Effect	Long-Run Effect
y	−0.68	0.41	−4.28	−6.20	−5.06	−5.99
c	0.45	0.16	−7.35	−8.18	−7.13	−8.22
k	0.00	0.41	0.00	−6.20	0.00	−5.99
Percentage point changes						
tb/y	−2.47	0.22	2.16	−0.20		
i/y	1.64	−0.00	−1.29	−0.00	0.11	−0.00
r	−0.00	−0.00	−0.00	−0.00	−0.00	−0.00
l	−0.14	0.08	−0.90	−1.05	−1.04	−1.01
m	−0.67	−0.00	−2.87	0.00	−3.59	−0.00

Table 12: SHORT-RUN ELASTICITY OF US CAPITAL TAX BASE

	Elasticity	y_1	l_1	m_1
Empirical estimates	[0.1, 0.5]			
Model Implications for the U.S.				
exog. utilization & $\theta = 1$	−0.09	0.04%	0.011	
exog. utilization & $\theta = 0.2$	−0.09	0.08%	0.028	
endog. utilization & $\theta = 0.2$	0.29	−0.15%	0.010	−0.471
Model Implications for the EU15				
exog. utilization & $\theta = 1$	−0.04	0.01%	0.004	
exog. utilization & $\theta = 0.2$	−0.02	0.03%	0.008	
endog. utilization & $\theta = 0.2$	0.32	−0.14%	0.004	−0.393

Note: Elasticity is measured as the percentage decrease of capital tax base in the first year after a 1% increase in the capital tax rate is introducede. For empirical estimates, see Gruber and Rauh (2007) and Dwenger and Steiner (2012). y_1 and m_1 provides the percent deviation from the initial steady state in the impact year. l_1 denotes the percentage points change from the initial steady state.

Table 13: Model Parameters

Parameter		Value
Discount Factor	β	0.96
Risk Aversion	σ	1.00
Avg. Income	y	0.79
Low household wealth	b_0^L	0.00
Avg. Gov. Consumption	μ_g	0.18
Autocorrel. G	ρ_g	0.88
Std Dev Error	σ_g	0.017
Initial Gov. Debt	B_0	0.79
Output Cost Default	ϕ_0	0.02

Note: Government expenditures, income and debt values are derived using Eurostat data for France, Germany, Greece, Ireland, Italy, Spain and Portugal.