Exit expectations in currency unions

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Abstract

The adoption of a common currency is not irreversible. In this paper, we develop a model of a small open economy which is initially part of a currency union. We show that, first, if fiscal policy fails to stabilize public debt, expectations of regime change arise necessarily in equilibrium. A regime change implies an alternative fiscal policy or, through exit from the union, monetary autonomy. Second, if monetary policy is expected to revalue debt after exit, interest rates rise prior to exit, reflecting redenomination risk. We explore the quantitative implications of redenomination risk by calibrating the model to Greek data.

Keywords: Currency union, exit, fiscal policy, regime change, redenomination risk, euro, Greek crisis, Markov-switching linear rational expectations model

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1 Introduction

Currency unions provide a nominal anchor to inflation-prone member states (Alesina and Barro, 2002). Delegating monetary policy to a hawkish central bank reduces inflation bias and thus differences in nominal interest rates across member states. The euro area is a case in point. Figure 1 displays monthly yield spreads on government bonds for Italy, Spain, Ireland, and Greece relative to Germany: they fell strongly in the run up to the creation of the euro in 1999 and stayed close to zero for about a decade. Their rise after 2009, at times of protracted budget deficits and large public liabilities, is often interpreted as a compensation for the possibility of an outright sovereign default (Lane, 2012). Yet, in addition to such credit risk, these yield spreads may also reflect "fears of a reversibility of the euro" (ECB, 2013). Indeed, expectations of a member state's exit from the union may give rise to redenomination risk: if bonds are expected to be converted into a new, weaker currency, their prices decline prior to exit, driving up yields.[1]

In this paper, we ask why redenomination risk may arise within a currency union and to what extent it differs from credit risk. We find that lack of fiscal discipline—typically considered a major cause for sovereign credit risk—may, in fact, also cause redenomination risk. Moreover, in terms of macroeconomic implications, redenomination risk, in contrast to credit risk, tends to undermine the stability gains of currency-union membership. Building on the New Keynesian small open economy framework developed by Galí and Monacelli (2005) and others, we develop a model which allows policy regimes to change over time and assume that agents are fully aware of this possibility. Policy regimes are captured by simple feedback rules for monetary and fiscal policy. Initially, there is no independent monetary policy, as the economy is assumed to be part of a currency union. At the same time, it lacks fiscal discipline. In the terminology of Leeper (1991), fiscal policy is "active" as it does not adjust (sufficiently) in a "passive" manner to stabilize debt. In principle, an active fiscal policy is sustainable as long as the price level is free to adjust in order to bring about a change in the real value of government debt (Woodford 1995, Cochrane 2001, and Sims 2013). Yet, in a small open economy which is a member of a currency union, (relative) purchasing power parity ties down the domestic price level in the long-run.

Against this background and similar in spirit to Davig and Leeper (2007a), we establish a first result: under the fiscal rule in place, an equilibrium obtains only if market participants expect

[1]For the euro area, there is evidence of exit expectations from the online betting markets (Shambaugh, 2012). In February 2012 Buiter and Rahbari (2012) coined the term "Grexit" and suggest a "likelihood of a Greek exit to 50% over the next 18 months". In May 2012 the German Ifo-think tank published a report on "Greece's exit from European Monetary Union: historical experience, macroeconomic implications and organisational implementation", see Born et al. (2012).

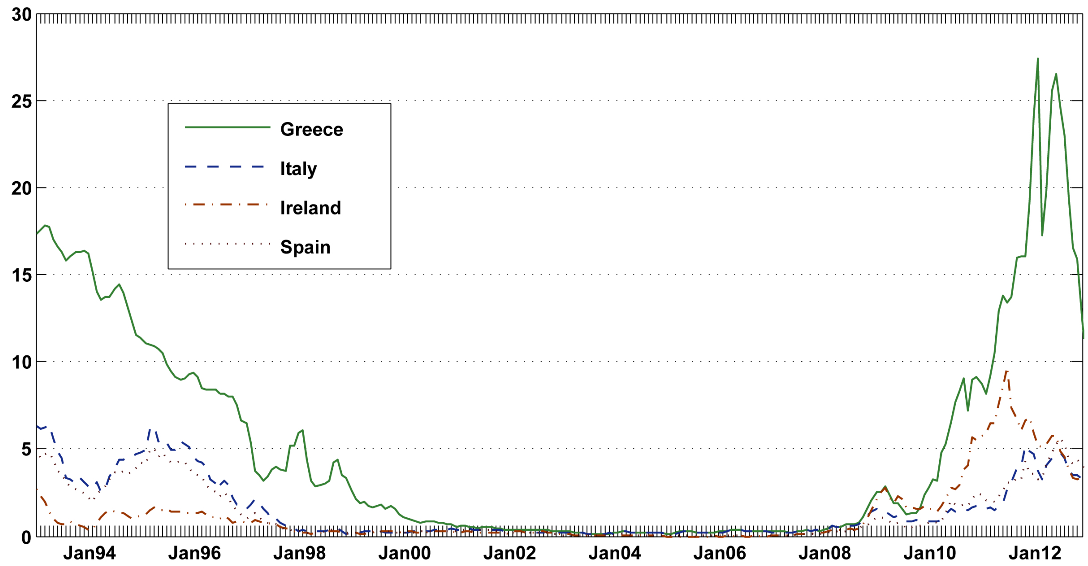

Figure 1: Interest rate spread vis-à-vis Germany. Notes: Long-term interest rates for convergence purposes, monthly observations 1993:1–2012:12; source: ECB (Data Appendix C).

a regime change to take place at some point.[2] Intuitively, expectations about regime change arise necessarily in equilibrium, because active fiscal policy is inconsistent with permanent union membership. In terms of policy regime change, we assume the systematic conduct of either i) fiscal or ii) monetary policy to adjust.

In the first case, the country alters its fiscal rule while retaining membership in the currency union. The new fiscal rule is passive and ensures sufficient budget surpluses to service the outstanding debt in real terms. In addition, we assume that at the time of regime change there is a credit event, as a haircut is applied to outstanding government debt. This gives rise to credit risk while the government accumulates debt under the initial regime.

In the second case, the country exits the currency union and starts operating an independent monetary policy which accommodates active fiscal policy. More precisely, monetary policy adjusts interest rates less than one-for-one to inflation thereby permitting a revaluation of public debt. The new policy regime is thus inflationary, which we show to be necessary and sufficient for expectations of a depreciation to arise under the initial regime. Given expectations of exit and depreciation upon exit, redenomination risk emerges in the initial regime.

[2]Formally, we allow for policy regimes to change within a Markov-Switching Linear Rational Expectations model. Davig and Leeper (2007a) use this framework to generalize the Taylor principle by showing that equilibrium determinacy obtains under a policy rule which would give rise to equilibrium indeterminacy in a fixed-regime model, provided there are expectations of a switch to a policy rule which is sufficiently aggressive towards inflation. In contrast, in our setup, the expected regime change ensures mean square stability rather than determinacy (Farmer et al., 2009).

Redenomination risk and credit risk differ. Redenomination risk drives up yields in the entire (small open) economy, while credit risk only drives up sovereign yields. This has important consequences for how government debt impacts the economy under the initial regime. In case there is only credit risk, higher sovereign yields compensate investors for the expected haircut and the remaining debt stock is known to be serviced once the new fiscal rule is put in place. Accordingly, Ricardian equivalence obtains already under the initial regime.

Instead, if there is redenomination risk, government debt is stagflationary to the extent that prices adjust sluggishly after exit. Intuitively, domestic residents face rising real interest rates, given expected real depreciation, and thus reduce expenditures which fall more-than-proportionally on domestically produced goods. At the same time, inflation takes off already before the actual exit takes place due to forward-looking price-setting decisions. This, in turn, induces a decline in competitiveness. As in case of the classic inflation bias of Barro and Gordon (1983), inflationary policies—expected to be put in place after the current regime is abandoned for lack of consistency—make themselves felt well ahead of time.

In order to assess the empirical relevance of these insights, we turn to the European sovereign debt crisis, notably the macroeconomic developments in Greece between late 2009 and early 2012. The upward revision of the fiscal deficit at the beginning of this period presumably supports the notion of an active fiscal policy. In due course, the macroeconomic outlook deteriorated further, fueling speculation of a "Grexit". Eventually, debt was restructured in early 2012, as fiscal reform was supposedly under way. We calibrate the model to account for these developments, exposing it to the time series of actual primary deficits. Time-series data for private and sovereign yield spreads suggest that redenomination risk accounted for about 10 percent of the rise in sovereign spreads. Moreover, while we find that market beliefs about an exit have been small, redenomination risk did have a nonnegligible impact on the stagflationary developments observed in Greece during our sample period.

Our analysis relates to earlier work on the stability of currency regimes. In fact, the notion that lack of fiscal discipline fuels speculation regarding the duration of a fixed exchange rate regime dates back to at least Krugman (1979). In his seminal analysis, the depletion of foreign currency reserves precipitates the fall of an exchange rate peg.[3] Within a currency union this may not happen. Still, other factors may drive speculation of exit and currency depreciation, such as the inability of fiscal policy to stabilize government debt at given prices.

A number of papers have analyzed the conduct of fiscal policy in currency unions from the

[3] Otherwise arbitrage possibilities remain unexploited in equilibrium. In our analysis, instead, yields adjust to equalize expected returns on different interest-bearing securities. If capital is imperfectly mobile, a central bank may try to defend an exchange rate peg by engineering a limited rise of domestic interest rates (Lahiri and Végh 2003).

perspective of the fiscal theory of the price level, which is also operative in parts of our analysis. The focus of these contributions are the implications of the fiscal rule in one or several large member countries for the entire union (Woodford 1996, Sims 1997, Bergin 2000). One noteworthy result is that pursuing an active fiscal policy may be in a member state's interest, as this raises its wealth at the expense of the rest of the union. In contrast, we analyze the case of a small open economy and abstract from developments in the rest of the union. As a result, we find that active fiscal policy gives rise to redenomination risk.

Models that allow for changes in policy regimes have become increasingly popular. Most notably, our work is related to Davig and Leeper (2007b) and Bianchi and Ilut (2012), who put forward models where the monetary/fiscal policy mix changes over time. Yet their analyses are confined to closed-economy models. Andolfatto and Gomme (2003) analyze a model with changes in money growth rules and imperfect information. They find that within low inflation regimes expectations of high inflation drive up interest rates leading to an economic downturn, which bears similarity to the effects of redenomination risk in our analysis.

The remainder of the paper is organized as follows. Section 2 presents the model and characterizes the properties of a solution. Section 3 establishes our main results and illustrates the macroeconomic implications of redenomination risk. In Section 4, we apply the model to Greek data. Section 5 concludes.

2 The model

Our model builds on the New Keynesian small open economy framework (Galí and Monacelli, 2005). We focus on a single country which is sufficiently small so as to have a negligible impact on the rest of the world. Within the country a representative household consumes, saves and works, while monopolistically competitive firms produce a variety of goods. They are constrained in their pricing decisions à la Calvo. The country relates to the rest of the world insofar as consumption is a composite of goods produced at home and abroad and firms export part of their production. Furthermore, saving takes place via a complete set of internationally traded state-contingent securities. The government issues one period nominal debt in order to finance lump-sum transfers. Government debt is riskless in the baseline version of the model, an assumption which we relax in our analysis below. We capture monetary and fiscal policy through simple feedback rules, distinguishing two possibilities in each case. Regarding monetary policy, the options are either to maintain a currency union with the rest of the world or to operate an independent monetary policy. The fiscal rule either stabilizes public debt at given prices or fails to do so.

Our model permits these policy rules to change, in a way consistent with agents' expectations.

Indeed, as stressed by Davig and Leeper (2007a), once it is recognized that policy regimes may differ across time, it is desirable to endow agents in the model economy with this very insight. In order to keep the analysis tractable, we assume exogenously given beliefs of regime change within a Markov-Switching Linear Rational Expectations (MS-LRE) model.[4] In what follows, we directly present the model in MS-LRE form and delegate the derivation of non-linear equilibrium conditions to Appendix A.

2.1 Equilibrium conditions and policy regimes

Our analysis is based on a first-order approximation to the optimality conditions of households and firms, the market clearing conditions as well as to the policy rules. The approximation is valid around a deterministic steady state, which is the same for every policy regime, with balanced trade, zero inflation and purchasing power parity. In what follows, we refer to variables in terms of deviations from this steady state using small-case letters. Note also that we only consider shocks which arise in the domestic economy, leaving the rest of the world unaffected.

A first set of equilibrium conditions is *invariant across policy regimes*. The dynamic IS equation and the open-economy New Keynesian Phillips curve are, in turn, given by

$$y_t = E_t y_{t+1} - \frac{\varpi}{\gamma}(r_t - E_t \pi_{H,t+1}), \quad (2.1)$$

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \kappa \left(\varphi + \frac{\gamma}{\varpi}\right) y_t. \quad (2.2)$$

Here E_t is the expectations operator, $\pi_{H,t}$ denotes domestic (producer price) inflation ($\pi_{H,t} = p_{H,t} - p_{H,t-1}$), y_t denotes output and r_t is the nominal interest rate.[5] As for parameters, the discount factor of the household is given by β, the coefficient of constant relative risk aversion by γ and the inverse of the Frisch elasticity by φ. We further define $\varpi := 1 + \omega(2-\omega)(\sigma\gamma - 1)$ and $\kappa := (1-\beta\xi)(1-\xi)/\xi$, where σ denotes the trade price elasticity and ω the weight of imports in the production of final goods. $1-\xi$ is the fraction of firms which are randomly selected to adjust prices within a given period.

Under complete international financial markets output is tied to the terms of trade s_t, the price of exports relative to imports,

$$y_t = -\frac{\varpi}{\gamma} s_t, \quad (2.3)$$

$$s_t = p_{H,t} + e_t. \quad (2.4)$$

[4]In a stylized two-period model of exchange-rate policies, Drazen and Masson (1994) make beliefs about regime change a function of both the credibility of policy makers and the state of the economy.

[5]More generally, while the country maintains membership to a currency union, it is the nominal interest rate on securities issued under domestic jurisdiction, see the discussion further below.

The second equation relates the terms of trade to domestic producer prices and the variable e_t. It represents the nominal exchange rate in terms of deviation from steady state, defined as the price of domestic currency in terms of foreign currency. In case the country maintains a currency union with the rest of the world, both share a common currency or, equivalently, the relative price of "currencies" is unity. Still, also in this case, it is useful to distinguish between domestic and foreign currency as a way to keep track of the jurisdiction under which securities are issued. While all securities are denominated in common currency, "domestic securities" are issued under domestic jurisdiction and "foreign securities" issued under foreign jurisdiction. This distinction becomes relevant if the country exits the union. Upon exit, domestic securities are converted into new currency, whereas foreign securities are not.[6] More specifically, we assume that domestic securities are converted at par into new currency and that the price of the new currency adjusts to clear the foreign exchange market.

As regards fiscal policy, we posit that the government levies lump sum taxes and issues one-period debt. We measure real public debt $\hat{d}_t$ and tax receipts $\hat{t}_t^r$ in terms of steady-state output, and express them in percentage point deviation from steady state (indicated by a hat). We assume that the government issues debt in its own currency, or equivalently, under domestic jurisdiction. Moreover, government debt is nominally riskless. The evolution of government debt is thus given by

$$\beta \hat{d}_t^r = \hat{d}_{t-1}^r + \zeta(\beta r_t - \pi_{H,t}) - \hat{t}_t^r, \tag{2.5}$$

where ζ denotes the debt-to-GDP ratio in steady state.[7]

A second set of equilibrium relationships *varies across policy regimes*. Specifically, regarding tax collections we posit the following fiscal rule:

$$\hat{t}_t^r = \psi_{\varsigma_t} \hat{d}_{t-1}^r - \varepsilon_t^d, \tag{2.6}$$

where the subscript ς_t indicates that the parameter ψ (which measures the responsiveness of taxes to the level of debt) follows a discrete-time Markov chain $\{\varsigma_t\}$ which determines the evolution of policy regimes over time. Monetary policy also possibly differs across regimes. In case of membership in the currency union, we impose $e_t = 0$. Alternatively, if monetary policy

[6] In practice, the conversion of securities in the course of a currency reform is likely to depend on the jurisdiction under which securities are issued. For instance, the discussion of a possible Grexit suggests that securities issued under Greek law were expected to be converted into new currency upon exit (see, for example, Buiter and Rahbari 2012). Similarly, historical examples of "forcible conversions" of debt issued in foreign currency, but under home law highlights the role of jurisdiction for currency conversions (Reinhart and Rogoff 2011).

[7] If the government were to issue debt under foreign jurisdiction equation (2.5) would feature an additional term capturing changes in the relative price of "currencies".

is independent, we assume it to follow an interest rate feedback rule, while the exchange rate adjusts to clear the foreign exchange market.

Altogether we consider the following three policy regimes, reflecting the particular interest of our analysis:

$$\text{Union AF:} \qquad e_t = 0, \qquad \psi < 1 - \beta, \tag{2.7 - 1}$$

$$\text{Union PF:} \qquad e_t = 0, \qquad \psi > 1 - \beta, \tag{2.7 - 2}$$

$$\text{Float AF:} \qquad r_t = \phi_\pi \pi_{H,t}, \quad \psi < 1 - \beta, \quad \phi_\pi < 1. \tag{2.7 - 3}$$

In the first and third regime, ψ is small such that taxes do not adjust sufficiently to stabilize outstanding debt, that is, fiscal policy is active (AF). Instead, given the specific assumptions on the Markov chain that we impose below, tax collections suffice to stabilize the level of outstanding debt at given prices in the second regime, a situation of passive fiscal policy (PF). The "AF/PF" suffix thus characterizes the fiscal rule. The first two regimes are characterized by a membership in a currency union. In the third regime the country operates an independent, but passive monetary policy, accommodating active fiscal policy: it adjusts nominal interest rates less than one-for-one to inflation.

2.2 Equilibrium and stability

We are now in a position to define an equilibrium, following Farmer et al. (2011). First, we restate equations (2.1) - (2.7) more compactly:

$$\Gamma_{\varsigma_t} x_t = E_t x_{t+1} + \Psi_{\varsigma_t} \varepsilon_t^d, \quad \varsigma_t \in \{\text{Union AF, Union PF, Float AF}\}, \tag{2.8}$$

where $x_t = (y_t, r_t, \pi_{H,t}, p_{H,t}, e_t, s_t, \hat{t}_t^r, \hat{d}_t^r)'$ and $\pi_{H,t} = p_{H,t} - p_{H,t-1}$. The matrices Γ_{ς_t} and Ψ_{ς_t} contain the model's deep parameters and ς_t indicates that they are regime dependent. Regime transitions are governed by a matrix $P = [p_{ij}] = [Prob(\varsigma_t = j; \varsigma_{t-1} = i)]$ specified below.

Definition 1. A rational expectations equilibrium is a mean square stable (MSS) stochastic process that, given the Markov chain $\{\varsigma_t\}$, satisfies equation (2.8).

Definition 2. An $n-$dimensional process $\{x_t\}$ is MSS if there exists an $n-$vector x_∞ and an $n \times n$ matrix Σ_∞ such that

- $\lim_{n \to \infty} E_t[x_{t+n}] = x_\infty$
- $\lim_{n \to \infty} E_t[x_{t+n}\ x_{t+n}'] = \Sigma_\infty$.

Note that the concept of stability as defined above differs somewhat from stability as it is commonly applied in fixed-regime models. Intuitively, explosive trajectories in some regimes are not an issue, if the economy does not stay in these regimes for too long. What matters is that trajectories are not globally explosive, which is ruled out by MSS. The duration of a regime is thus key for stability. It is governed by the transition matrix on which we impose a specific structure:

$$P = \begin{pmatrix} \mu & (1-\mu)\lambda & (1-\mu)(1-\lambda) \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad 0 \leq \mu \leq 1, \quad 0 < \lambda < 1. \tag{2.9}$$

It implies that regime one is transitory (unless $\mu = 1$), while regimes two and three are absorbing states. Graphically, our Markov chain specifies the following sequence of regime transitions:

$$\text{Union AF}_{\circlearrowleft \mu} \qquad \longrightarrow_{1-\mu} \qquad \begin{cases} \lambda & \text{Union PF}_{\circlearrowleft 1}, \\ 1-\lambda & \text{Float AF}_{\circlearrowleft 1}. \end{cases}$$

Thus, initially there is membership in a monetary union paired with an active fiscal policy. In any period, the economy stays in Union AF with probability μ, and leaves this regime with probability $1-\mu$. λ, in turn, is the probability weight of a change in the fiscal rule. By contrast, a change in the conduct of monetary policy, that is, exit from the monetary union, takes place with probability $1-\lambda$. In this case, the fiscal rule is assumed to remain unchanged. Importantly, we assume that λ lies within the open interval $(0,1)$, so that if the initial policy regime is up for change, there is uncertainty about which policy will adjust; neither continued membership in the union nor an exit can be ruled out. Finally, note that Union PF and Float AF are absorbing states, in the sense that these regimes will remain in place indefinitely.[8]

Generally, the solution of MS-LRE models is obtained through specific algorithms (Farmer et al., 2011). Under our assumptions on the transition probabilities, the problem simplifies considerably. Since the two target regimes are absorbing, we are able to solve the model backwards using the method of undetermined coefficients. This is particularly useful, because we can thereby ensure the uniqueness of the solution, as the method of undetermined coefficients always delivers all candidate solutions. For the parameter specifications which we consider,

[8] Assuming absorbing states allows us to keep the analysis tractable. At the same time we acknowledge that reentering a monetary union or resorting to active fiscal policies in the future cannot be ruled out in practice. Yet we abstract from these possibilities as their effect on the equilibrium outcome in the initial regime is bound to be small.

we find that at most one of the candidate solutions satisfies mean square stability.[9] Appendix B solves the MS-LRE in its most general form, including credit risk as introduced in section 3.2 below.

3 Redenomination risk

We now investigate why redenomination risk may arise in a currency union and explore its consequences. In a nutshell, we show that it reflects an inconsistency in the current policy regime—a lack of both fiscal discipline and monetary autonomy. In terms of consequences, redenomination risk turns out to have far reaching macroeconomic implications, as it induces public debt to be stagflationary.

3.1 Why redenomination risk arises

We start from the basic observation that interest rates reflect expectations of future policies via a version of the uncovered interest parity (UIP) condition. Combine equations (2.1), (2.3) and (2.4) to obtain

$$r_t = -E_t(\Delta e_{t+1}). \tag{3.1}$$

This condition holds under all policy regimes, but the case of a currency union is of particular interest. In this case $e_t = 0$, while $e_{t+1} \neq 0$ only if the country exits the currency union. The nominal interest rate r_t corresponds to the yield of a one-period discount bond issued under domestic jurisdiction, which pays off one unit of common currency if no exit occurs, and one unit of new currency if exit does occur. More precisely, r_t is the spread in the yield of such a bond relative to one issued under foreign jurisdiction. The latter pays one unit of common currency in all states of the world. It represents the *spread*, because variables are expressed in terms of deviation from steady state and we only consider shocks originating in the domestic economy, such that yields on foreign securities are constant.[10]

Condition (3.1) holds in equilibrium and rules out arbitrage possibilities as market participants are able to trade both domestic and foreign securities. Imagine that exit from the

[9]Note that in general MS-LRE models may have multiple fundamental ('non-sunspot') equilibria, see Farmer et al. (2011) for an example. In our analysis, we consider MSS solutions of the form $x_t = F_{\varsigma_t} x_{t-1} + G_{\varsigma_t} \varepsilon_t^d \;\; \forall \varsigma_t$.

[10]The relation which underlies equation (3.1) is given by $r_t - r_t^* = -E_t(\Delta e_{t+1})$, where r_t^* is the yield of a one-period discount bond issued under foreign jurisdiction (in terms of deviation from steady state). As returns in common currency are not influenced by developments in the small member state under consideration, we have $r_t^* = 0$. More fundamentally, (3.1) results from combining two Euler equations $\gamma c_t = \gamma c_{t+1} - (r_t - E_t \pi_{t+1})$ and $\gamma c_t = \gamma c_{t+1} - (r_t^* - E_t \Delta e_{t+1} - E_t \pi_{t+1})$, which in turn are linearizations of the two asset pricing equations $R_t^{-1} = E_t(\rho_{t,t+1})$ and $R_t^{*-1}/\mathcal{E}_t = E_t(\rho_{t,t+1}/\mathcal{E}_{t+1})$. Here $\mathcal{E}_t$ is the nominal exchange rate, π_t is CPI inflation, c_t is consumption and R_t^{-1} and R_t^{*-1} denote the prices of discount bonds issued under domestic and foreign jurisdiction, respectively, with the payoff structure described in the main text above. $\rho_{t,t+1}$ is the stochastic discount factor. See also Appendix A.

currency union cannot be ruled out and that, upon exit, the newly created domestic currency is expected to depreciate ($E_t(\Delta e_{t+1}) < 0$). In this case, domestic discount bonds must promise high returns in equilibrium, as foreign discount bonds pay off strictly better (in terms of new domestic currency) in those states of the world where exit and depreciation occurs. The level of r_t therefore measures redenomination risk. In our model, public debt in excess of its steady-state level gives rise to redenomination risk in regime Union AF, as we establish in the following proposition.

Proposition 1. *Given the transition matrix* (2.9)*, any rational expectations equilibrium satisfying the conditions summarized in* (2.8) *features expectations of a policy regime change (that is, it requires $\mu < 1$). Moreover, expectations about currency depreciation upon exit increase in the level of outstanding public debt.*

Proof. We prove the first part by assuming to the contrary that there are no expectations of a regime change ($\mu = 1$). We show that in this case there is no rational expectations equilibrium, exploiting the fact that absent regime change the existence of a MSS process requires variables to be on non-explosive trajectories in each regime (Farmer et al. 2009). We proceed by showing that public debt is on an explosive trajectory in regime Union AF. First, absent expectations about regime change, $r_t = 0$ by (3.1). Second, combine (2.2),(2.3) and (2.4) to obtain

$$\beta E_t(p_{H,t+1}) = (1 + \beta + \frac{\kappa\varphi\varpi}{\gamma} + \kappa)p_{H,t} - p_{H,t-1}, \tag{3.2}$$

which has a unique non-explosive solution given by $p_{H,t} = \phi p_{H,t-1}$, where $\phi = \phi_{\text{aux}}/2\beta - \sqrt{\phi_{\text{aux}}^2/4\beta^2 - 1/\beta}$ with $\phi_{\text{aux}} = 1 + \beta + \kappa\varphi\varpi/\gamma + \kappa$, so that ϕ lies between zero and one. This expression illustrates that (relative) purchasing power parity pins down the domestic price level in the long run. Third, combine the equations for debt (2.5) and taxes (2.6) to obtain

$$\beta\hat{d}_t^r = (1 - \psi)\hat{d}_{t-1}^r + \zeta(\beta r_t - \pi_{H,t}) + \varepsilon_t^d. \tag{3.3}$$

This equation shows that debt is on an explosive trajectory, as $1 - \psi > \beta$ and both the evolution of r_t and $\pi_{H,t}$ are isolated from the level of debt and deficit shocks under Union AF. Thus, there is no equilibrium for $\mu = 1$.

Now turn to the second part of the proposition. We focus on Float AF. As we establish in Appendix B, output and inflation in this regime evolve as

$$\begin{aligned} \pi_{H,t} &= \phi_{\pi,d}\hat{d}_{t-1}^r + \phi_{\pi,\varepsilon}\varepsilon_t^d, \\ y_t &= \phi_{y,d}\hat{d}_{t-1}^r + \phi_{y,\varepsilon}\varepsilon_t^d, \end{aligned}$$

where $\phi_{\pi,d}, \phi_{\pi,\varepsilon}, \phi_{y,d}$ and $\phi_{y,\varepsilon}$ are strictly positive coefficients. Combining (2.3) and (2.4), we solve for the nominal exchange rate as a function of the endogenous state variables $p_{H,t-1}$

and $\hat{d}^r_{t-1}$ and the shock ε^d_t:

$$\begin{aligned} e_t &= -\frac{\gamma}{\varpi} y_t - p_{H,t} \\ &= -p_{H,t-1} - (\frac{\gamma}{\varpi}\phi_{y,d} + \phi_{\pi,d})\hat{d}^r_{t-1} - (\frac{\gamma}{\varpi}\phi_{y,\varepsilon} + \phi_{\pi,\varepsilon})\varepsilon^d_t. \end{aligned}$$

Assuming that the economy operates under regime Union AF at time $t-1$, the nominal interest rate is given by

$$r_{t-1} = -E_{t-1}(\Delta e_t) = (1-\mu)(1-\lambda)\left(p_{H,t-1} + (\frac{\gamma}{\varpi}\phi_{y,d} + \phi_{\pi,d})\hat{d}^r_{t-1}\right).$$

Here we use $e_{t-1} = 0$, $E_{t-1}(\varepsilon^d_t) = 0$ and the fact that the exchange rate moves only in case of an exit from the currency union. Given that $\varpi > 0$ and $\varphi > 0$, expected depreciation (and therefore redenomination risk) increases in the level of outstanding public debt. □

The above result rests on the fact that public debt is on an explosive trajectory in case permanent union membership is coupled with active fiscal policy.[11] Recalling the classic analysis of Leeper (1991), union membership for a small country thus appears as an instant of "active" monetary policy: it is not allowing the price level to adjust in order to stabilize the real value of public debt, because its conduct is decided at the union level and by assumption unresponsive to developments in a small member state. In this regard, Proposition 1 makes a positive statement: active fiscal policy within a currency union is feasible, provided that market participants expect a regime change to take place at some point.[12] Given that regime change implies also the possibility of an exit ($\lambda < 1$), it follows immediately from Proposition 1 that any equilibrium will feature exit expectations under Union AF. At the same time, there will be expectations of a depreciation upon exit, as monetary policy is expected to revalue the debt stock upon exit. Under Union AF, a build-up of public debt will therefore be accompanied by a rise in redenomination risk.

Our result hinges critically on the assumption that the domestic economy is small. Sims (1997, 1999) and Bergin (2000) analyze the implications of an active fiscal policy in large member states of a currency union. They are quite different. In fact, a large member state may sustain an active fiscal policy indefinitely, provided monetary policy is passive at the union level, thereby allowing the inflationary consequences of a member state's active fiscal policy to be felt across the entire union. The resulting incentive of a member state to pursue an active fiscal policy provides a rationale for constraining the conduct of fiscal policy within

[11] We note that private sector transversality conditions do not constrain public debt to be on a non-explosive path in the present open-economy context. Still, it is unappealing to allow governments to run Ponzi-schemes (Sims 1997). In any case, we restrict our analysis to (mean square) stable equilibria as defined above.

[12] Davig and Leeper (2011) also consider a policy regime featuring active monetary and fiscal policy for a limited period within a regime-switching model.

a currency union. Our analysis, instead, shows that pursing an active fiscal policy is not necessarily in the interest of a small member state to the extent that it may fuel speculation of an exit from the union.[13]

The above discussion highlights that active fiscal policy coupled with expectations about accommodative monetary policy upon exit are sufficient for redenomination risk to arise under the initial regime. The following proposition establishes the converse. For this purpose, we consider an alternative scenario where fiscal policy is passive in all regimes. In this case, redenomination risk in the initial policy regime is absent in all equilibria. In addition, there is an equilibrium where exit is not expected.

Proposition 2. *Consider the equilibrium conditions summarized in system* (2.8)*, but assume that* $\psi > 1 - \beta$ *in all regimes. Given the transition matrix* (2.9)*, there is an equilibrium where regime change is not expected* ($\mu = 1$)*. Moreover, within the class of minimal-state-variable solutions, expectations about currency depreciation upon exit are absent in all equilibria.*

Proof. We prove the first part of the proposition by recognizing that absent regime change ($\mu = 1$), the existence of an MSS process is equivalent to all variables being on non-explosive trajectories in all regimes in isolation. Start with union membership. Along the lines of the proof of Proposition 1, $r_t = 0$ by (3.1) and $p_{H,t} = \phi p_{H,t-1}$ with $0 < \phi < 1$. Given $1 - \psi < \beta$, the autoregressive root in equation (3.3) is strictly smaller than one. Hence, public debt is on a non-explosive trajectory. Next, we establish non-explosiveness under the float. Combining (2.1), (2.2) and the feedback rule for monetary policy implies

$$\begin{pmatrix} 1 & \frac{\varpi}{\gamma} \\ 0 & \beta \end{pmatrix} E_t \begin{pmatrix} y_{t+1} \\ \pi_{H,t+1} \end{pmatrix} = \begin{pmatrix} 1 & \frac{\varpi}{\gamma}\phi_\pi \\ -\kappa(\varphi + \frac{\gamma}{\varpi}) & 1 \end{pmatrix} \begin{pmatrix} y_t \\ \pi_{H,t} \end{pmatrix}. \tag{3.4}$$

The minimum-state-variable solution to (3.4) is given by $y_t = 0$ and $\pi_{H,t} = 0$. As a consequence, debt evolves as follows: $\beta \hat{d}_t^r = (1 - \psi)\hat{d}_{t-1}^r + \varepsilon_t^d$. Again, it is non-explosive as fiscal policy is passive: $1 - \psi < \beta$.

Now turn to the second part of the proposition. Under the float we have as minimum-state-variable solution $y_t = 0$ and $\pi_{H,t} = 0$ as part of all equilibria (that is: also for $\mu < 1$), and, by (2.3) and (2.4), $\Delta e_t = 0$. Hence, there is no expected depreciation prior to exit from the union.[14] □

[13] As a technical matter, the small open economy which we consider is of measure zero (Galí and Monacelli 2005) such that variables, even those on explosive trajectories, have no impact on the rest of the world. In the present context, one may question the small-open-economy assumption on conceptual grounds. Still, if we were to relax the assumption, the results in Bergin (2000) suggest that Proposition 1 still holds provided that monetary policy is active at the union level and permanent transfers across member states are ruled out.

[14] If monetary policy were assumed active upon exit ($\phi_\pi > 1$), the minimum-state-variable solution just discussed would at the same time be the only non-explosive solution under the float.

Taken together Propositions 1 and 2 show that lack of fiscal discipline causes redenomination risk within a small member state of a currency union. Our result hinges on the assumption that if a country exits the union for lack of fiscal discipline, it will likely accommodate active fiscal policy upon exit by means of its new monetary autonomy (passive monetary policy)—an assumption which strikes us as plausible. That said, we stress that even though redenomination risk is fundamentally justified under Union AF, it also provokes a further deterioration of fundamentals through its impact on the government's financing cost (see Section 3.2). Thus, there is the possibility that an autonomous shift in expectations regarding regime change causes fiscal policy to become active, even if it is passive in the absence of such a shift. We do not analyze this possibility in the present paper.[15]

3.2 Redenomination risk vs credit risk

Redenomination risk arises as market participants expect domestic securities to be converted into new currency and, in addition, the new currency to depreciate upon exit. Depreciation, in turn, is expected whenever deficit shocks push public debt beyond its steady-steady level. In order to clarify how redenomination risk impacts the economy, we contrast it to credit risk, the latter arising if market participants expect the government to apply a haircut to its outstanding liabilities in some states of the world.

We modify the model to account for this possibility: we assume that a credit event takes place at the time of the switch to the new fiscal regime, thereby capturing a scenario of fiscal reform coupled with a one-time default.[16] Specifically, in case of a credit event, the government repudiates the amount $\delta_t > 0$ of its debt obligations, proportional to outstanding debt in excess of the steady-state level:

$$\delta_t = \zeta^{-1}\delta\hat{d}^r_{t-1}, \tag{3.5}$$

where $\delta \in [0, 1]$ is the haircut applied to excess debt.[17] Otherwise, we assume $\delta_t = 0$. As a

[15] Specifically, in case of a membership in the currency union, condition $\psi > 1 - \beta$ is generally not sufficient for debt to be non-explosive, if expectations of an exit and depreciation arise. Because of the resulting risk premiums, the initial regime may become unsustainable, confirming expectations of the exit—the classic scenario of a self-fulfilling currency crisis (see, e.g., Obstfeld 1996). Above, however, we assume that fiscal policy is active independent of expectations regarding regime change.

[16] Alternatively, rather than switching to a passive fiscal rule, an active fiscal policy could be maintained forever, if debt repudiation adjusts endogenously so as to satisfy the government's intertemporal budget constraint (Uribe, 2006). As a result there is perpetual default which we rule out as inconsistent with membership in a currency union.

[17] Technically, the scenario of a one-time default at the time of the switch to Union PF introduces a new regime, see the solution to the full model in Appendix B.

result, the flow budget constraint of the government is now given by

$$\beta \hat{d}^r_t = \hat{d}^r_{t-1} + \zeta(\beta i_t - \delta_t - \pi_{H,t}) - \hat{t}^r_t \quad (3.6)$$

$$i_t = r_t + E_t(\delta_{t+1}), \quad (3.7)$$

where i_t is the nominal yield on government bonds (in terms of deviation from steady state) and thus measures the sovereign yield spread. Insert (3.1) into (3.7) and apply the law of iterated expectations to obtain the following decomposition of sovereign yield spreads under Union AF:

$$i_t = -(1-\mu)(1-\lambda)E_t(e_{t+1}|\text{Float AF}) + (1-\mu)\lambda\delta_{t+1}. \quad (3.8)$$

The first term captures redenomination risk. It affects nominal interest rates of domestic securities, or "private yield spreads", in general. The second term captures credit risk which only affects the sovereign yield spread. Thus, sovereign yield spreads exceed private yield spreads to the extent that partial repudiation of public debt is expected.

We now explore the distinct role of credit and redenomination risk in the transmission of deficit shocks while the economy operates under regime Union AF. For this purpose we rely on model simulations using parameter values in line with our calibration of the model to Greek data, detailed in Section 4.1 below. An exception are the parameters λ and δ which we vary in what follows. Figure 2 displays impulse responses of selected variables to a one-time deficit shock. While horizontal axes measure time in quarters, vertical axes measure deviations from steady state, either in percent or percentage points of steady-state output. We show results for the two polar cases: a scenario where there is only redenomination risk ($\lambda = 0.5$, $\delta = 0$), represented by solid lines, and a scenario where there is only credit risk ($\lambda \to 1$, $\delta = 0.5$), represented by dashed lines. In each instant, market participants attach some probability on regime change taking place in the next period. Still, in the scenarios under consideration regime change does not actually materialize, such that Union AF is maintained for the entire period under consideration.[18]

The upper left panel displays the deficit shock. It is assumed to be purely transitory and equal to one percent of steady-state output. In response to the shock, public debt (upper right panel) and sovereign yields (2^{nd} row left panel) rise steadily, irrespectively of whether there is only credit risk or only redenomination risk. This is because—under Union AF—neither taxes nor the price level adjust (sufficiently) to stabilize the real value of public debt. As debt builds up, expected losses to be realized in some states of the world also increase. Investors are compensated by lower bond prices, such that the sovereign yield spread and public debt

[18] Put differently, yield spreads reflect expected losses which are not observed in the sample under consideration, as in the case of "peso problems". Conceptually related is the notion of a "rare disaster", which may account for within-sample deviation from interest rate parity (Barro, 2006).

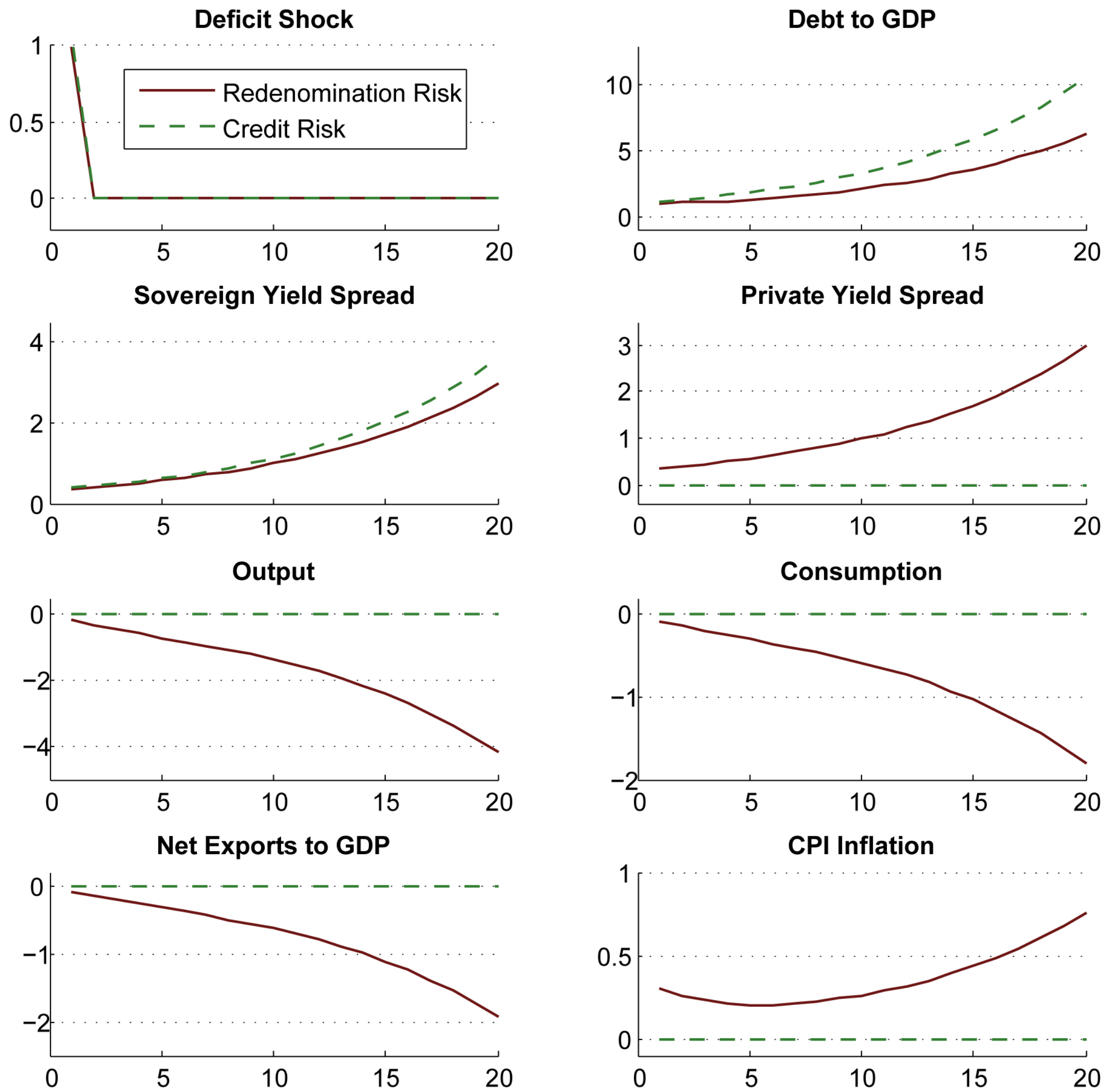

Figure 2: Impulse responses to a deficit shock conditional on staying in regime Union AF. Notes: deficit shock equal to one percent of (annual) steady-state GDP. Horizontal axes measure quarters. Vertical axes measure deviations from steady state in percent, and percentage points in case of debt to GDP, net exports to GDP and the deficit shock (annual steady-state GDP in all cases). CPI inflation and the interest rates are annualized. Formal definitions of all variables are given in Appendix A.

rise further. As a result, the size of the necessary adjustment, be it through outright default or through exit and inflation, increases in the duration of the initial regime.

The dynamic adjustment of the economy differs fundamentally, however, depending on whether there is only credit risk or only redenomination risk. In the former case (dashed lines) the deficit shock has no bearing on the economy other than on public finances. Importantly, in the absence of redenomination risk, private yield spreads r_t are zero (2^{nd} row right panel). Thus, while the government's refinancing costs rise with credit risk, private-sector interest rates remain unaffected.[19] Furthermore, in the absence of redenomination risk, the remaining debt stock (once the haircut has been applied) is known to be serviced eventually—once the switch to Union PF has taken place. Ricardian equivalence thus obtains even under Union AF: deficits are neutral in that they have no allocative consequences (Barro, 1974).[20]

By contrast, in case there is only redenomination risk (solid lines), private yield spreads rise with the build-up in public debt (Proposition 1). In this case deficits have allocative consequences. Output (3^{rd} row left panel) declines along with consumption (3^{rd} row right panel) and net exports (lower left panel). At the same time, inflation rises (lower right panel). Hence, deficit shocks turn out to be stagflationary in the presence of redenomination risk. Moreover, we note that a one-time deficit shock induces long-lasting effects—the model generates substantial internal propagation.

To better understand the economy's response to deficit shocks in the presence of redenomination risk, we conduct an additional experiment where exit from the currency union materializes in period 10. To simplify the discussion, we again assume that there is no credit risk ($\lambda = 0.5$, $\delta = 0$). Figure 3 shows the responses of selected variables. We contrast results for the baseline case (solid lines) with those for an alternative setup, where price rigidity upon exit declines to an intermediate level (solid lines with squares) or disappears altogether (solid line with circles).[21]

The upper left panel shows the response of the nominal exchange rate. Upon exit there is a discrete downward shift and further, more gradual depreciation thereafter. The exchange rate

[19] Through a sovereign risk channel sovereign credit risk may affect the effective borrowing and savings conditions in the private sector, too (Corsetti et al., 2013a). We also note that in our complete-markets setup there are no distributional effects associated with government default.

[20] This result also holds for the non-linear model and independently of the size of the haircut parameter. On the one hand, fewer taxes are required to service outstanding debt *ex post* if the haircut is large. On the other hand, if the (expected) haircut is large, the stock of debt grows faster *ex ante* through higher bond yields. If bonds are priced correctly, both effects offset each other, leaving the expected present value of future taxes unchanged. Yet, if taxes are assumed to be distortionary, credit risk has allocative consequences (Bi, 2012).

[21] This is to highlight that rigidity *upon exit* is crucial for our results. In fact, the same pattern obtains if price rigidity declines globally, i.e. also in the initial regime. Technically, to allow for the possibility of a change in rigidity, we modify the Phillips curve in regime Union AF such that firms anticipate that the frequency of price adjustment changes with a change in the regime. The derivation of the modified Phillips curve is available on request.

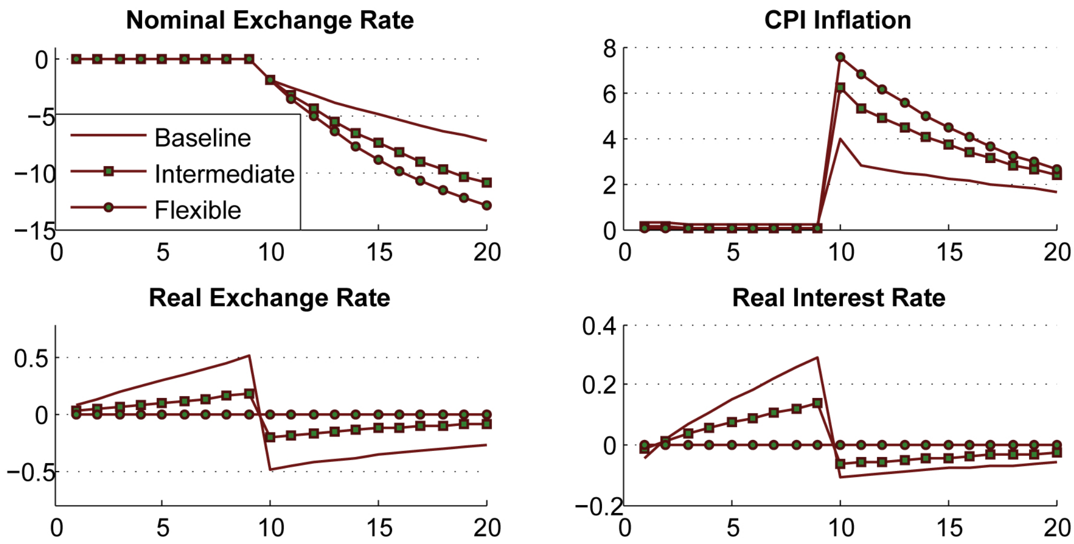

Figure 3: Impulse responses to a deficit shock in regime Union AF, with exit from the currency union occuring in period 10, for different levels of price rigidity upon exit. Horizontal axes measure quarters. Vertical axes measure deviations from steady state in percent. The solid line corresponds to the baseline case (unchanged price rigidity); squares indicate an intermediate degree of price rigidity ($\xi = 0.75$), and circles indicate flexible prices after exit. CPI inflation and the real interest rate are annualized. Formal definitions of all variables can be found in Appendix A.

response is stronger, the more flexible prices are in the new regime. This is consistent with the response of inflation (upper right panel): it increases sharply in case prices are flexible after exit. While inflation also takes up in the baseline case, its response is muted relative to a scenario of more flexible prices. In fact, if prices are fully flexible after exit, the real exchange rate does not adjust after exit (lower left panel). Instead, in the baseline case, the sluggish response of inflation after exit induces the real exchange rate to depreciate upon exit, along with the nominal exchange rate. Importantly, large devaluations tend to be associated with a strong decline of the real exchange rate, as prices tend to adjust more sluggishly than the nominal exchange rate—as in our baseline calibration (Burstein et al., 2005).[22]

Prior to exit, equilibrium requires that an expected real depreciation is met by increased real interest rates (lower right panel).[23] Households thus postpone expenditure until after exit.[24]

[22]Burstein et al. (2005) consider five large devaluations and find that the real exchange rate response is on average about 90 percent of the nominal exchange rate response. In our baseline calibration, this ratio is about 50 percent, while in case prices are flexible upon exit it is zero, see Figure 3.

[23]This follows from condition (3.1), once it is expressed in real terms.

[24]In fact, the decline of consumption depends on the degree of good-market integration. In the absence of consumption home bias, consumption remains constant even as real yields on domestic securities rise, because in this case the consumption-based real interest rate is unaffected by developments in the small open economy.

Moreover, consumption is on a declining trajectory, since the size of adjustment increases the longer the initial regime lasts (see Figure 2). Finally, inflation rises prior to exit, implying an appreciation of the real exchange rate which, in turn, accounts for the decline of net exports. Intuitively, forward looking firms tend to raise prices, given that they expect inflation and depreciation upon exit which, in turn, will raise marginal costs.[25] Hence, the inflationary policies which are expected to take place after exit make themselves felt already prior to exit, as the current policy regime is bound to be abandoned for lack of consistency. In this sense, the implications of redenomination risk are reminiscent of the classic inflation bias of Barro and Gordon (1983).

4 The case of Greece 2009–2012

We now turn to Greek data for the period 2009–2012 in order to explore the empirical relevance of the mechanism analyzed above. According to our analysis, given market beliefs about regime change, a build-up of public debt will be accompanied by a rise in credit and redenomination risk. The latter induces both a decline of economic activity and a loss of competitiveness. In what follows, we use the model to quantify the contribution of redenomination risk to macroeconomic outcomes in Greece.

As discussed in the introduction, the Greek government faced spiralling financing costs starting in late 2009, as did several other governments in the euro area (see Figure 1 above). Yet the experience of Greece is most dramatic in terms of sovereign yield spreads. In addition, the scenario of an exit from the euro area was arguably most plausible in the case of Greece. Finally, the size and persistence of fiscal deficits arguably support the notion of an active fiscal policy, both prior to and during the crisis. This makes the case of Greece particularly suitable to be studied through the lens of our model.

In what follows we focus on the period 2009Q4–2012Q1. The beginning of this period coincides with the take-off of sovereign yield spreads, shortly after the incoming government announced a substantial overshooting of the previous government's projection for the 2009 budget deficit, from 6 to 12.7 percent of GDP (Gibson et al. 2012). We limit our analysis to the period prior to the restructuring of Greek public debt in March/April 2012 because we are interested in the repercussions of an expected regime change, rather than of the regime change itself. Note that before the restructuring Greek public debt—in line with our modelling assumption—was

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In our calibration, we assume that domestically produced goods account for 80% of steady-state consumption, in line with data for Greece, see Section 4.

[25]In a closed-economy model, Davig and Leeper (2007b) also find that deficit shocks are inflationary in a regime of passive fiscal policy, if agents anticipate a switch to a regime of active fiscal policy, where the latter regime is associated with high levels of inflation.

Table 1: Model calibration

	Parameter description	Value	Target / Source
β	Discount factor (steady state)	0.99	Annual interest rate 4.1%
γ	Risk aversion	1	Balanced growth
φ	Inverse Frisch elasticity	3	Domeij and Flodén (2006)
σ	Trade-price elasticity	1.5	Bennett et al. (2008)
ω	Home-bias	0.2	Export-to-GDP ratio 2009
ξ	Fraction of unchanged prices	0.9	Flat Phillips curve
ϵ	Elasticity of substitution	11	Mark-up 10%
ϕ_π	Taylor-rule coefficient	0.9	Passive monetary policy
ψ	Tax-rule coefficient	0.009/0.02	Active/Passive fiscal policy
ζ	Steady-state debt-to-GDP ratio	5.13	128.3% Debt 2009Q3
δ	Haircut	0.519	51.9% Haircut 2012Q1
μ	Probability of staying in initial regime	0.78	Δ Private yield spread
λ	Haircut vs exit	0.945	Δ Sovereign yield spread

issued almost exclusively under Greek jurisdiction (see, e.g., Buiter and Rahbari 2012 and Buchheit et al. 2013). Appendix C provide a detailed description of the data used in this section.

4.1 Calibration

We use observations for the Greek economy, if available, to pin down the parameter values of the model. They are displayed in Table 1. A period in the model corresponds to one quarter. The discount factor β is set to 0.99. We assume that the coefficient of relative risk aversion, γ, takes a value of one, consistent with balanced growth. We set $\varphi = 3$, implying a Frisch elasticity of labor supply of 1/3 in line with evidence provided by Domeij and Flodén (2006). The trade-price elasticity σ is set to 1.5, in line with estimates for Greece by Bennett et al. (2008), and ω to 0.2, corresponding to the 2009 export-to-GDP ratio in Greece. We set $\epsilon = 11$, such that the steady-state mark-up is equal to 10 percent.

To capture price rigidities we set $\xi = 0.9$, implying a fairly flat Phillips curve, in line with evidence for the recent crisis period (see, e.g., IMF 2013). Regarding fiscal policy, we assume $\psi = 0.02$ for the regime where fiscal policy is passive, while we assume $\psi = 0.009$ in case fiscal policy is active. At the same time, we assume $\phi_\pi = 0.9$ such that monetary policy upon exit is passive. The policy coefficients and the slope of the Phillips Curve are hard to pin down empirically, and we discuss below how alternative values would affect our results.

We determine a last set of parameter values by matching key features of the Greek economy during the period 2009Q4–2012Q1. Specifically, given that yield spreads have been very low before 2009Q4, we assume that the model is in steady state prior to our sample period and set $\zeta = 5.13$ in order to match the debt-to-GDP ratio of 128.3 percent in 2009Q3. Finally,

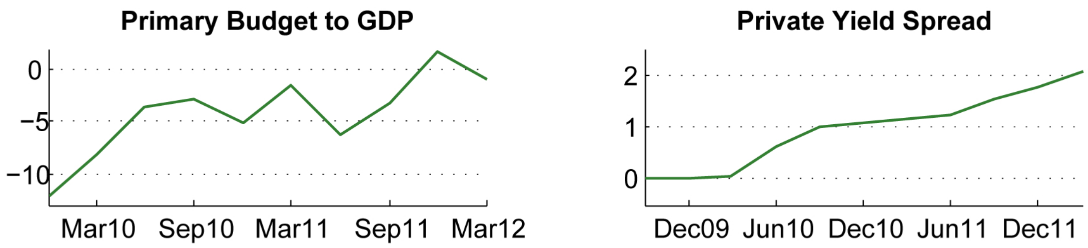

Figure 4: Primary budget balance (left) and private-sector yield spreads (right) in Greece. Spreads are computed relative to Germany, based on interest rates earned on deposits of non-financial institutions and households with domestic banks. Notes: Horizontal axis measure quarters. Vertical axis measure percent of (annual) GDP for the primary deficit, percent annualized for interest rates.

we set $\delta = 0.519$ implying an effective expected haircut of 51.9 percent, corresponding to the actual value at the end of 2012Q1 (Zettelmeyer et al., 2013).

In order to pin down the parameters μ and λ, which capture the beliefs regarding regime change, we target the actual increase in yield spreads during the sample period. We assume that the economy operates under the regime Union AF and expose it to a sequence of deficit shocks corresponding to the actual values during the period under consideration. Figure 4 displays actual time-series data of primary budget deficits (left panel) and private-sector yield spreads (right panel) for Greece. As in the case of sovereign yield spreads (see Figure 1) they are computed relative to Germany.[26] We rely on interest rates earned on deposits, as deposits with domestic banks would arguably be converted into new currency upon exit, thus proxying for "domestic securities" as defined above. Yield spreads based on interest rates on within-country loans give very similar results. The joint identification of μ and λ is possible, because sovereign yield spreads increase in both credit and redenomination risk, while private yield spreads increase only in the latter. Our calibration yields values for $\mu = 0.78$ and $\lambda = 0.945$, implying a probability of exit of 1.3 percent from one quarter to the next, and of 20.7 percent of an outright default.

4.2 Redenomination risk and credit risk in Greece

We now confront the predictions of the model with actual developments in Greece during the period 2009Q4–2012Q1. Recall that the model features shocks to the government budget as the only exogenous source of variation. Throughout the model economy is assumed to operate under regime Union AF, even though expectations of regime change are a key for the equilibrium outcome.

[26]Here and below, actual data are normalized in line with our assumption that the economy has been in steady state initially.

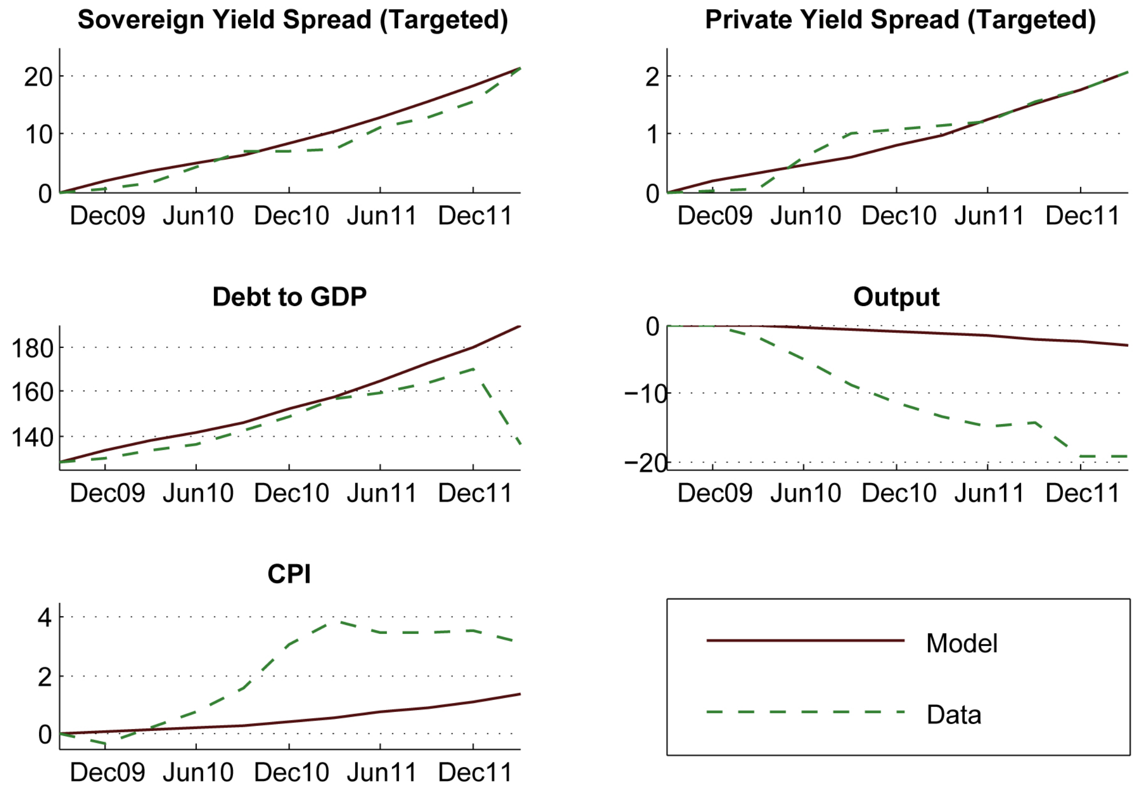

Figure 5: Model prediction (solide lines) versus Greek data (dashed lines) for selected variables. Notes: change of sovereign and private sector yield spreads over sample period serve as calibration target. Horizontal axis measures quarters. Vertical axis measures change in percent, and percentage points in case of debt to GDP. CPI inflation and the interest rates are annualized. Data is normalized to zero in 2009Q3; first observation: 2009Q4. Output and the CPI increase are detrended using a euro area average.

Figure 5 displays model predictions (solid lines) as well as actual developments (dashed lines) for selected variables. The top row shows the evolution of yield spreads vis-à-vis Germany: the evolution of sovereign and private yield spreads are shown in the left and right panel, respectively. While the increase in spreads during the sample period serves as a calibration target, the model's prediction tracks the actual evolution of spreads rather closely. From a quantitative point of view, the rise in sovereign spreads amounts to about 10 times the rise in private spreads. This suggests that sovereign yield spreads in Greece have been mostly driven by credit risk. Redenomination risk, instead, accounts for merely 10 percent of the rise in sovereign spreads, as it is simultaneously reflected in private yields spreads.

The middle and lower left panels of Figure 5 show the evolution of important economic indicators. Starting with the model's prediction for public debt (2^{nd} row left panel), we note

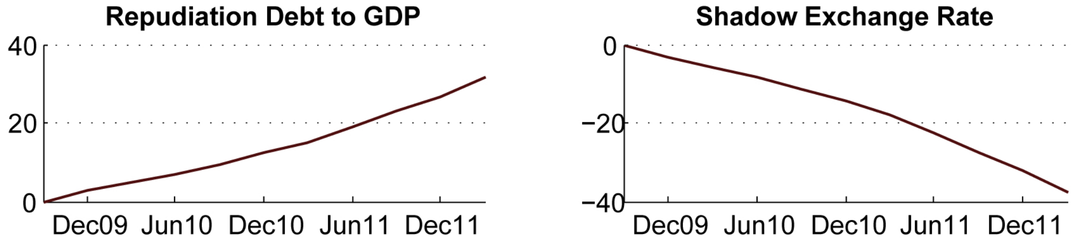

Figure 6: Debt repudiation and shadow exchange rate. Vertical axis measures percentage point changes for debt-to-GDP in haircut scenario, relative changes in percent for the nominal exchange rate; horizontal axis measures quarters.

that it tracks actual developments rather closely.[27] The model's prediction for output (2$^{\text{nd}}$ row right panel) and the CPI (lower left panel) fall short of actual developments. Indeed, assuming a steeper Phillips curve or lower policy coefficients would result in a somewhat smaller predicted output decline. Intuitively, in this case, the exit regime would be more inflationary and hence lower exit probabilities are necessary in order to account for the increase in private yield spreads (λ increases). As a result, the real effects of redenomination risk would be muted.

Taken together, we conclude that redenomination risk accounts for up to 1/5 of the output decline observed during the sample period and for up to 1/2 of the loss of competitiveness measured by the CPI increase. Given that in the absence of exit expectations deficit shocks would be neutral for the allocation even under the initial regime, these findings suggest that redenomination risk made a nonnegligible contribution to the stagflationary developments in Greece during the recent crisis.

This finding may seem puzzling, given that market beliefs about exit have been small according to our calibration. Yet it is important to keep in mind that both credit and redenomination risk rise endogenously as long as the initial regime persists and adjustment is delayed. In order to quantify this effect we compute the expected losses in the event of an outright default and in the event of an exit. Figure 6 shows the results. In the left panel, we report the percentage-point reduction in the debt-to-GDP ratio had the Greek government applied a haircut to its outstanding liabilities. It rises in close sync with the rise in the debt level, pushing up the credit risk premium. By the same token, the right panel in Figure 6 shows the source of redenomination risk. It reports the "shadow exchange rate", that is, the depreciation of the

[27] As discussed above, the restructuring of Greek debt has taken place at the end of 2012Q1, hence the drop of the debt-to-GDP ratio at the end of the sample. Note that, by contrast, the average sovereign spread in 2012Q1 did not decline (spreads were 24.1 percent in January, 27.4 percent in February and 17.2 percent in March, see Figure 1). The same is true for spreads in the private sector.

"new Drachma" vis-à-vis the euro had Greece exited the currency union (Flood and Garber 1984). Again, it rises over time in close sync with the evolution of debt, as inflation upon exit is expected to be higher, the higher the current debt level—in line with the fundamental insight of the fiscal theory of the price level.[28]

5 Conclusion

In this paper we ask why redenomination risk may arise within a currency union and to what extent it differs from credit risk. Our analysis is based on a small open economy model which allows policy regimes to change while agents are fully aware of this possibility. Policy regimes differ in that i) a country may be a member of a currency union or operate an independent monetary policy and ii) it may lack fiscal discipline or not.

As a first result, we show that lack of fiscal discipline is inconsistent with union membership. Yet an equilibrium may still obtain, provided that market participants expect a regime change to take place at some point. Such a regime change may require either adopting fiscal discipline or exiting the currency union. In the event of an exit, monetary autonomy permits stabilizing the real value of public debt through higher inflation. This brings about expectations of depreciation of the new vis-à-vis the former currency. As a result, redenomination risk emerges while the country is still member of the currency union.

As a second result, we show that the effects of redenomination risk differ from those of credit risk. Credit risk emerges because of a non-zero probability of an outright default on government debt. For a given debt level, credit risk raises sovereign bond yields, but has no further bearing on the economy. Redenomination risk, in contrast, raises private sector bond yields. To the extent that prices upon exit adjust sluggishly, this crowds out private expenditure. At the same time, forward-looking firms tend to raise prices accounting for a possible exit coupled with a depreciation of the new currency.

We explore the empirical relevance of redenomination risk, as we interpret the macroeconomic developments in Greece during the period 2009Q4–2012Q1 through the lens of our model. Specifically, we calibrate the model to capture key aspects of Greek data, notably the increase of sovereign and private sector yield spreads, while exposing it to the time series of actual primary deficits. For our sample period, we find a quarter-to-quarter probability of exit

[28]It is instructive to compare our results regarding exit to those of Barro (2006) about rare disasters. In our setup, losses in the event of exit rise endogenously, amounting to almost 40% at the end of the sample period. The (per-quarter) probability of the event is 1.3 percent. As a result, redenomination risk equals approximately 2 percentage points. Barro obtains a 3.5% equity risk premium, given a (per-annum) disaster probability of 1.7% and losses conditional on a disaster occurring in the range of 30% on average. In Barro (2006) lower expected losses thus give rise to a somewhat larger premium, most likely because he considers a non-linear setup.

from the euro area of 1.3 percent and a probability of outright default of 20.7 percent. The increase in private sector yield spreads is about 1/10 of the increase in sovereign yield spreads, suggesting a limited role for redenomination risk in accounting for the increase of sovereign yield spreads. Still, we find that redenomination risk accounts for up to 1/5 of the output decline and for up to 1/2 of the loss of competitiveness in Greece during the period under consideration. Against this background, we conclude that "fears of a reversibility of the euro", while quantitatively moderate, may still have contributed to the stagflationary developments in Greece during the recent crisis.

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A Model

In what follows, we present the non-linear model, along with first order and market clearing conditions, as well as details on the log-linearization. Our exposition draws on Corsetti et al. (2013b), focusing on the domestic economy and its interaction with the rest of the world, ROW, for short.

A.1 Non-linear model

Final Good Firms The final consumption good, C_t, is a composite of intermediate goods produced by a continuum of monopolistically competitive firms both at home and abroad. We use $j \in [0,1]$ to index intermediate good firms as well as their products and prices. Final good firms operate under perfect competition and purchase domestically produced intermediate goods, $Y_{H,t}(j)$, as well as imported intermediate goods, $Y_{F,t}(j)$. Final good firms minimize expenditures subject to the following aggregation technology

$$C_t = \left[(1-\omega)^{\frac{1}{\sigma}} \left(\left[\int_0^1 Y_{H,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}} \right)^{\frac{\sigma-1}{\sigma}} + \omega^{\frac{1}{\sigma}} \left(\left[\int_0^1 Y_{F,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}} \right)^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \quad \text{(A.1)}$$

where σ measures the trade price elasticity. The parameter $\epsilon > 1$ measures the price elasticity across intermediate goods produced within the same country, while ω measures the weight of imports in the production of final consumption goods—a value lower than one corresponds to home bias in consumption.

Expenditure minimization implies the following price indices for domestically produced intermediate goods and imported intermediate goods, respectively,

$$P_{H,t} = \left(\int_0^1 P_{H,t}(j)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}, \qquad P_{F,t} = \left(\int_0^1 P_{F,t}(j)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}}. \quad \text{(A.2)}$$

By the same token, the consumption price index is

$$P_t = \left((1-\omega) P_{H,t}^{1-\sigma} + \omega P_{F,t}^{1-\sigma} \right)^{\frac{1}{1-\sigma}}. \quad \text{(A.3)}$$

Regarding the ROW, we assume an isomorphic aggregation technology. Further, the law of one price is assumed to hold at the level of intermediate goods such that

$$P_{F,t} \mathcal{E}_t = P_t^*, \quad \text{(A.4)}$$

where $\mathcal{E}_t$ is the nominal exchange rate (the price of domestic currency in terms of foreign currency). P_t^* denotes the price index of imports measured in foreign currency. It corresponds to the foreign price level, as imports account for a negligible fraction of ROW consumption. We also define the terms of trade and the real exchange rate as

$$S_t = \frac{P_{H,t}}{P_{F,t}}, \; Q_t = \frac{P_t \mathcal{E}_t}{P_t^*} \tag{A.5}$$

respectively. Note that while the law of one price holds throughout, deviations from purchasing power parity (PPP) are possible in the short run, due to home bias in consumption.

Intermediate Good Firms Intermediate goods are produced on the basis of the following production function: $Y_t(j) = H_t(j)$, where $H_t(j)$ measures the amount of labor employed by firm j. Intermediate good firms operate under imperfect competition. We assume that price setting is constrained exogenously à la Calvo. Each firm has the opportunity to change its price with a given probability $1 - \xi$. Given this possibility, a generic firm j will set $P_{H,t}(j)$ in order to solve

$$\max E_t \sum_{k=0}^{\infty} \xi^k \rho_{t,t+k} \left[Y_{t,t+k}(j) P_{H,t}(j) - W_{t+k} H_{t+k}(j) \right], \tag{A.6}$$

where $\rho_{t,t+k}$ denotes the stochastic discount factor and $Y_{t,t+k}(j)$ denotes demand in period $t + k$, given that prices have been set optimally in period t.

Households The domestic economy is inhabited by a representative household that ranks sequences of consumption and labour effort, $H_t = \int_0^1 H_t(j) dj$, according to the following criterion

$$E_t \sum_{k=0}^{\infty} \beta^k \left(\frac{C_{t+k}^{1-\gamma}}{1-\gamma} - \frac{H_{t+k}^{1+\varphi}}{1+\varphi} \right). \tag{A.7}$$

The household trades a complete set of state-contingent securities with the rest of the world. Letting Ξ_{t+1} denote the payoff in units of domestic currency in period $t + 1$ of the portfolio held at the end of period t, the budget constraint of the household is given by

$$W_t H_t + \Upsilon_t - T_t - P_t C_t = E_t \left\{ \rho_{t,t+1} \Xi_{t+1} \right\} - \Xi_t, \tag{A.8}$$

where T_t and Υ_t denotes lump-sum taxes and profits of intermediate good firms, respectively.

Monetary and Fiscal Policy In case the economy is not part of a currency union, domestic monetary policy is specified by an interest rate feedback rule. Defining the riskless one period interest rate as $R_t \equiv 1/E_t(\rho_{t,t+1})$, we posit

$$\log(R_t) = \log(R) + \phi_\pi (\Pi_{H,t} - \Pi_H), \tag{A.9}$$

where $\Pi_{H,t} = P_{H,t}/P_{H,t-1}$ measures domestic inflation and (here as well as in the following) variables without a time subscript refer to the steady-state value of a variable. Conversely, if the country is part of a currency union the exchange rate is exogenously fixed at unity, $\mathcal{E}_t = 1$.

In terms of fiscal policy, we assume that the government levies lump sum taxes, T_t, and issues a one-period discount bond, D_t. It is issued under domestic jurisdiction, paying off one unit of domestic currency tomorrow. Debt is risky as the government may default on a fraction $\delta_t \in [0, 1]$ of its outstanding liabilities. The period budget constraint of the government then reads as follows:

$$I_t^{-1} D_t = (1 - \delta_t) D_{t-1} - T_t, \tag{A.10}$$

where I_t^{-1} is the price of the discount bond. The following no-arbitrage condition holds in equilibrium:

$$I_t^{-1} = E_t(\rho_{t,t+1}(1 - \delta_{t+1})). \tag{A.11}$$

It links the price of bonds to the expected losses in the event of an outright default. Next, defining $D_t^r := D_t/P_{H,t}Y$ and $T_t^r := T_t/P_{H,t}Y$ as a measure of real debt and tax revenues to steady state GDP, we posit that

$$T_t^r - T^r = \psi(D_{t-1}^r - D^r) - \varepsilon_t^d. \tag{A.12}$$

ε_t^d measures an iid shock to tax collections, or, equivalently a "deficit shock".

Market clearing At the level of each intermediate good, supply equals demand of final good firms and the ROW:

$$Y_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} \left((1 - \omega)\left(\frac{P_{H,t}}{P_t}\right)^{-\sigma} C_t + \omega \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\sigma} C_t^*\right), \tag{A.13}$$

where $P_{H,t}^*$ and C_t^* denote the price index of domestic goods expressed in foreign currency and ROW consumption, respectively. It is convenient to define an index for aggregate domestic output: $Y_t = \left(\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right)^{\frac{\epsilon}{\epsilon-1}}$. Substituting for $Y_t(j)$ using (A.13) gives the aggregate relationship

$$Y_t = (1 - \omega)\left(\frac{P_{H,t}}{P_t}\right)^{-\sigma} C_t + \omega \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\sigma} C_t^*. \tag{A.14}$$

We also define net exports in terms of steady-state output as follows:

$$\frac{1}{Y}\left(Y_t - \frac{P_t}{P_{H,t}} C_t\right). \tag{A.15}$$

A.2 Equilibrium conditions and the linearized model

In the following, lower-case letters denote the percentage deviation of a variable from its steady-state value, 'hats' denote (percentage point) deviations from steady state scaled by steady-state output. Variables in the ROW are assumed to be constant.

Price indices The terms of trade, the law of one price, the CPI, CPI inflation and the real exchange rate can be written as

$$s_t = p_{H,t} - p_{F,t}, \tag{A.16}$$

$$p_{F,t} = -e_t, \tag{A.17}$$

$$p_t = (1-\omega)p_{H,t} + \omega p_{F,t} = p_{H,t} - \omega s_t, \tag{A.18}$$

$$\pi_t = \pi_{H,t} - \omega \Delta s_t, \tag{A.19}$$

$$q_t = (1-\omega)s_t. \tag{A.20}$$

Intermediate good firms The demand for a generic good (j) is given by

$$Y_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} Y_t, \tag{A.21}$$

so that

$$\int_0^1 Y_t(j)dj = \zeta_t Y_t, \tag{A.22}$$

where $\zeta_t = \int_0^1 \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\varepsilon} dj$ measures price dispersion. Aggregation gives

$$\zeta_t Y_t = \int_0^1 H_t(j)dj = H_t. \tag{A.23}$$

A first order approximation is given by $y_t = h_t$.
The first order condition to the price setting problem is given by

$$E_t \sum_{k=0}^{\infty} \xi^k \rho_{t,t+k} \left[Y_{t,t+k}(j) P_{H,t}(j) - \frac{\varepsilon}{\varepsilon-1} W_{t+k} H_{t+k} \right] = 0. \tag{A.24}$$

In the steady state, we have a symmetric equilibrium:

$$P_H = \frac{\varepsilon}{\varepsilon-1}\frac{WH}{Y} = \frac{\varepsilon}{\varepsilon-1} MC^n, \tag{A.25}$$

where the second equation defines nominal marginal costs.

Linearizing (A.24) and using the definition of price indices, one obtains a variant of the New Keynesian Phillips curve (see, e.g., Galí and Monacelli, 2005):

$$\pi_{H,t} = \beta E_t \pi_{H,t+1} + \kappa mc_t^r, \tag{A.26}$$

where $\kappa := (1-\xi)(1-\beta\xi)/\xi$ and marginal costs are defined in real terms, deflated with the domestic price index

$$mc_t^r = w_t - p_{H,t} = w_t^r - \omega s_t. \tag{A.27}$$

Here $w_t^r = w_t - p_t$ is the real wage (deflated with the CPI).

Households The first order conditions in deviations from steady state are

$$w_t^r = w_t - p_t = \gamma c_t + \varphi h_t, \tag{A.28}$$

$$c_t = E_t c_{t+1} - \frac{1}{\gamma}(r_t - E_t \pi_{t+1}). \tag{A.29}$$

Risk sharing implies that consumption is tightly linked to the real exchange rate (see, e.g., Galí and Monacelli, 2005)

$$\gamma c_t = -q_t. \tag{A.30}$$

Government Rewriting the interest rate feedback rule gives

$$r_t = \phi \pi_{H,t}, \tag{A.31}$$

and similarly for the case of currency union membership, where $e_t = 0$.
Rewriting the the tax rule (A.12) gives

$$\hat{t}_t^r = \psi \hat{d}_{t-1}^r - \varepsilon_t^d. \tag{A.32}$$

Scale the flow budget constraint (A.10) by producer prices and steady state output, and linearize around zero default to obtain

$$\beta \hat{d}_t^r = \hat{d}_{t-1}^r + \zeta(\beta i_t - \delta_t - \pi_{H,t}) - \hat{t}_t^r, \tag{A.33}$$

where $\zeta := \frac{D}{PY}$ is debt-to-output ratio in steady state.
Next, using that $\rho_{t,t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-\gamma}\frac{P_t}{P_{t+1}}$, linearize the no-arbitrage condition (A.11) to obtain

$$c_t = E_t c_{t+1} - \frac{1}{\gamma}(i_t - E_t \delta_{t+1} - E_t \pi_{t+1}), \tag{A.34}$$

which, together with (A.29), establishes that $i_t = r_t + E_t(\delta_{t+1})$.

Equilibrium Linearizing the good market clearing condition (A.14) yields

$$y_t = -(2-\omega)\sigma\omega s_t + (1-\omega)c_t, \tag{A.35}$$

where we use the definition of the terms of trade (A.19) and the fact that variables in the ROW are constant. Net exports to GDP become

$$\hat{tb}_t = y_t - c_t + \omega s_t. \tag{A.36}$$

Some key equations We finally show how to obtain equations (2.1)-(2.3) given in the main text (which are the dynamic IS curve, the New Keynesian Phillips curve and a risk sharing condition).

Combine good market clearing (A.35), risk sharing (A.30) and the definition of the real exchange rate (A.20) to obtain

$$y_t = -\frac{1}{\gamma}\underbrace{(1+\omega(2-\omega)(\sigma\gamma-1))}_{:=\varpi} s_t. \tag{A.37}$$

Rearrange to obtain

$$s_t = -\frac{\gamma}{\varpi} y_t, \tag{A.38}$$

which is (2.3) in the main text.
Rewrite the Euler equation (A.29)

$$\begin{aligned} c_t &= E_t c_{t+1} - \frac{1}{\gamma}(r_t - E_t(\pi_{H.t+1} - \omega\Delta s_{t+1})) && \text{(A.39)} \\ &= E_t c_{t+1} - \frac{1}{\gamma}(r_t - E_t\pi_{H,t+1} - \frac{\omega\gamma}{\varpi}E_t\Delta y_{t+1}), && \text{(A.40)} \end{aligned}$$

where we use $\pi_t = \pi_{H,t} - \omega\Delta s_t$ in the first line and (A.38) in the second.
Combine (A.38) with (A.30) and (A.20) to obtain

$$c_t = \frac{1-\omega}{\varpi} y_t. \tag{A.41}$$

Use this expression to substitute for consumption in (A.40)

$$y_t = E_t y_{t+1} - \frac{\varpi}{\gamma}(r_t - E_t\pi_{H,t+1}), \tag{A.42}$$

which is (2.1) in the main text.
Finally, use (A.28), (A.38), (A.41) and production technology $y_t = h_t$ to rewrite marginal cost

$$mc_t^r = w_t^r - \omega s_t = \gamma c_t + \varphi h_t - \omega s_t = (\frac{\gamma}{\varpi} + \varphi) y_t. \tag{A.43}$$

Insert into the Phillips curve (A.26) to obtain (2.2) in the main text.

B Model solution

In what follows, we present details regarding the model solution. In a nutshell, we obtain mean square stable solutions by applying the method of undetermined coefficients. To begin with we follow Farmer et al. (2009) and Farmer et al. (2011) noting that Markov-Switching Linear Rational Expectations models (MS-LRE) have the following general structure:

$$\Gamma_{\varsigma_t} x_t = E_t x_{t+1} + \Psi_{\varsigma_t} \varepsilon_t \ \ \forall \varsigma_t, \tag{B.1}$$

with x_t being a vector of endogenous random variables, ε_t being a vector of white noise structural errors, and where Γ_{ς_t} and Ψ_{ς_t} are matrices containing the model's deep parameters. They evolve over time, following a discrete time Markov Chain $\{\varsigma_t\}$, with transition matrix $P = [p_{ij}] = [Prob(\varsigma_t = j; \varsigma_{t-1} = i)]$.

A candidate solution looks as follows:

$$x_t = F_{\varsigma_t} x_{t-1} + G_{\varsigma_t} \varepsilon_t \ \ \forall \varsigma_t, \tag{B.2}$$

and it is mean square stable (thus constitutes a rational expectations equilibrium to (B.1)) if and only if all eigenvalues of

$$(P' \otimes I_{n^2}) \text{diag}(F_{\varsigma_1} \otimes F_{\varsigma_1}, ..., F_{\varsigma_h} \otimes F_{\varsigma_h}) \tag{B.3}$$

lie within the unit circle. Here n is the number of variables considered, h denotes the number of regimes, $\otimes$ is the Kronecker-product and "diag" stacks matrices in a bigger diagonal matrix. Specifically, in the full model with outright default there are four distinct regimes, with transitions governed by

$$P = \begin{pmatrix} \mu & (1-\mu)\lambda & 0 & (1-\mu)(1-\lambda) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}. \tag{B.4}$$

Union PF from the main text is divided into two regimes (call them "Union PF - Default" and "Union PF"), the former being purely transitory to be left for the latter immediately. As detailed in the transition matrix above, we refer to Union PF as regime 3, to Union PF - Default as regime 2, and to Float AF as regime 4. Union AF corresponds to regime 1. In the following, we solve the model "backwards", starting with Union PF and Float AF, both of which are absorbing states. For each regime we obtain the coefficient matrices F_{ς_t} and G_{ς_t}.

Recall that the model features two endogenous state variables ($\hat{d}_t^r$ and $p_{H,t}$) and one shock (ε_t^d). We outline the derivation of the solution (B.2) for the state variables only, so that $n = 2$.

For convenience we restate the equilibrium conditions of the model:

$$\begin{aligned}
y_t &= E_t y_{t+1} - \frac{\varpi}{\gamma}(r_t - E_t \pi_{H,t+1}), && \text{(B.5)}\\
\pi_{H,t} &= \beta E_t \pi_{H,t+1} + \kappa\left(\varphi + \frac{\gamma}{\varpi}\right) y_t, && \text{(B.6)}\\
y_t &= -\frac{\varpi}{\gamma} s_t, && \text{(B.7)}\\
s_t &= p_{H,t} + e_t, && \text{(B.8)}\\
\beta \hat{d}_t^r &= \hat{d}_{t-1}^r + \zeta(\beta i_t - \pi_{H,t} - \delta_t) - \hat{t}_t^r, && \text{(B.9)}\\
i_t &= r_t + E_t(\delta_{t+1}), && \text{(B.10)}\\
\hat{t}_t^r &= \psi_{\varsigma_t} \hat{d}_{t-1}^r - \varepsilon_t^d, && \text{(B.11)}\\
\delta_t &= \zeta^{-1} \delta_{\varsigma_t}\, \hat{d}_{t-1}^r, && \text{(B.12)}\\
r_t &= \phi_\pi \pi_{H,t} \quad \text{or} \quad e_t = 0, && \text{(B.13)}
\end{aligned}$$

with inflation being defined by $\pi_{H,t} = p_{H,t} - p_{H,t-1}$.

Union PF Combine equations (B.5),(B.7),(B.8) to obtain the UIP-condition, and equations (B.6),(B.7),(B.8) to obtain a second order difference equation in the producer price index:

$$\begin{aligned}
r_t &= -E_t(\Delta e_{t+1}), && \text{(B.14)}\\
\beta E_t(p_{H,t+1}) &= \underbrace{(1 + \beta + \frac{\kappa\varphi\varpi}{\gamma} + \kappa)}_{\phi_{aux}} p_{H,t} - p_{H,t-1}. && \text{(B.15)}
\end{aligned}$$

Union PF is absorbing, thus $E_t(\Delta e_{t+1}) = 0$ and so $r_t = 0$. Prices are solved by $p_{H,t} = \phi p_{H,t-1}$, with $\phi = \phi_{aux}/2\beta - \sqrt{\phi_{aux}^2/4\beta^2 - 1/\beta} \in (0,1)$, where ϕ_{aux} is specified in (B.15). As there is no default in Union PF, $i_t = r_t = 0$ (B.10), and so

$$\beta \hat{d}_t^r = (1-\psi)\hat{d}_{t-1}^r - \zeta \pi_{H,t} + \varepsilon_t^d,$$

where we suppress the regime-dependence of ψ for expositional clarity.

More compactly:

$$\underbrace{\begin{bmatrix} p_{H,t} \\ \hat{d}_t^r \end{bmatrix}}_{x_t} = \underbrace{\begin{bmatrix} \phi & 0 \\ \frac{\zeta(1-\phi)}{\beta} & \frac{1-\psi}{\beta} \end{bmatrix}}_{=:F_3} \underbrace{\begin{bmatrix} p_{H,t-1} \\ \hat{d}_{t-1}^r \end{bmatrix}}_{x_{t-1}} + \underbrace{\begin{bmatrix} 0 \\ \frac{1}{\beta} \end{bmatrix}}_{=:G_3} \varepsilon_t^d.$$

Union PF - Default Regime Union PF - Default is purely transitory, and so $E_t(\delta_{t+1}) = 0$ also here (yielding again $i_t = 0$). Accordingly, Union PF and Union PF - Default differ only in the law of motion for public debt:

$$\underbrace{\begin{bmatrix} p_{H,t} \\ \hat{d}_t^r \end{bmatrix}}_{x_t} = \underbrace{\begin{bmatrix} \phi & 0 \\ \frac{\zeta(1-\phi)}{\beta} & \frac{1-\psi-\delta}{\beta} \end{bmatrix}}_{=:F_2} \underbrace{\begin{bmatrix} p_{H,t-1} \\ \hat{d}_{t-1}^r \end{bmatrix}}_{x_{t-1}} + \underbrace{\begin{bmatrix} 0 \\ \frac{1}{\beta} \end{bmatrix}}_{=:G_2} \varepsilon_t^d.$$

Float AF In regime Float AF, there is an independent central bank and no outright default ($i_t = r_t$). Insert the Taylor-rule into (B.5) and (B.9) to obtain a three-equation system in $(y_t, \pi_{H,t}, \hat{d}_t^r)$:

$$\begin{aligned} y_t &= E_t y_{t+1} - \frac{\varpi}{\gamma}(\phi_\pi \pi_{H,t} - E_t \pi_{H,t+1}), \\ \pi_{H,t} &= \beta E_t \pi_{H,t+1} + \kappa(\varphi + \frac{\gamma}{\varpi}) y_t, \\ \beta \hat{d}_t^r &= (1-\psi)\hat{d}_{t-1}^r + \zeta(\beta\phi_\pi - 1)\pi_{H,t} + \varepsilon_t^d. \end{aligned}$$

Now guess that $\pi_{H,t} = \phi_{\pi,d}\hat{d}_{t-1}^r + \phi_{\pi,\varepsilon}\varepsilon_t^d$ and $y_t = \phi_{y,d}\hat{d}_{t-1}^r + \phi_{y,\varepsilon}\varepsilon_t^d$ and substitute to obtain:

$$\pi_{H,t} = \underbrace{\frac{\phi_{\pi,d}(1-\psi) + \phi_{y,d}\kappa(\varphi + \frac{\gamma}{\varpi})}{1 - \phi_{\pi,d}\zeta(\beta\phi_\pi - 1)}}_{=\phi_{\pi,d}} \hat{d}_{t-1}^r + \underbrace{\frac{\phi_{\pi,d} + \phi_{y,\varepsilon}\kappa(\varphi + \frac{\gamma}{\varpi})}{1 - \phi_{\pi,d}\zeta(\beta\phi_\pi - 1)}}_{=\phi_{\pi,\varepsilon}} \varepsilon_t^d,$$

$$y_t = \underbrace{\frac{\phi_{y,d}(\frac{1-\psi}{\beta} + \frac{\phi_{\pi,d}\zeta}{\beta}(\beta\phi_\pi - 1)) - \frac{\phi_{\pi,d}\varpi}{\gamma\beta}(\beta\phi_\pi - 1)}{1 + \frac{\varpi}{\gamma}\frac{\kappa}{\beta}(\varphi + \frac{\gamma}{\varpi})}}_{=\phi_{y,d}} \hat{d}_{t-1}^r + \underbrace{\frac{\phi_{y,d}(\frac{1}{\beta} + \frac{\phi_{\pi,\varepsilon}\zeta}{\beta}(\beta\phi_\pi - 1)) - \frac{\phi_{\pi,\varepsilon}\varpi}{\gamma\beta}(\beta\phi_\pi - 1)}{1 + \frac{\varpi}{\gamma}\frac{\kappa}{\beta}(\varphi + \frac{\gamma}{\varpi})}}_{=\phi_{y,\varepsilon}} \varepsilon_t^d.$$

Verify the guess first for $\phi_{\pi,d}$ and $\phi_{y,d}$ to obtain a quadratic equation in $\phi_{\pi,d}$. The root which implies stable dynamics is given by $\phi_{\pi,d} = -p/2 + \sqrt{p^2/4 - q}$, where

$$\begin{aligned} p &= -\left(\frac{1}{\beta}(\beta - 1 + 2\psi) + \frac{\varpi\kappa}{\gamma\beta}(\varphi + \frac{\gamma}{\varpi})\right) / \frac{\zeta(\beta\phi_\pi - 1)}{\beta}, \\ q &= \left(\frac{\psi}{\beta}(\beta - 1 + \psi) + \frac{\varpi\kappa}{\gamma\beta}(\varphi + \frac{\gamma}{\varpi})(\beta\phi_\pi - 1 + \psi)\right) / \frac{\zeta^2(\beta\phi_\pi - 1)^2}{\beta}. \end{aligned}$$

Second, verify the guess for $\phi_{y,d}$ to arrive at

$$\phi_{y,d} = \frac{\phi_{\pi,d}\varpi(1 - \beta\phi_\pi)}{\varpi\kappa(\varphi + \gamma/\varpi) + \gamma(\beta - 1 + \psi) + \phi_{\pi,d}\zeta\gamma(1 - \beta\phi_\pi)}. \tag{B.16}$$

Finally, conjecture that $(1-\psi)\phi_{\pi,\varepsilon} = \phi_{\pi,d}$, and similarly, $(1-\psi)\phi_{y,\varepsilon} = \phi_{y,d}$. To check this, insert both expressions into the verified guess from the previous page.

More compactly:

$$\underbrace{\begin{bmatrix} p_{H,t} \\ \hat{d}^r_t \end{bmatrix}}_{x_t} = \underbrace{\begin{bmatrix} 1 & \phi_{\pi,d} \\ 0 & \frac{1-\psi+\zeta(\beta\phi_\pi-1)\phi_{\pi,d}}{\beta} \end{bmatrix}}_{=:F_4} \underbrace{\begin{bmatrix} p_{H,t-1} \\ \hat{d}^r_{t-1} \end{bmatrix}}_{x_{t-1}} + \underbrace{\begin{bmatrix} \phi_{\pi,\varepsilon} \\ \frac{\zeta(\beta\phi_\pi-1)\phi_{\pi,\varepsilon}+1}{\beta} \end{bmatrix}}_{=:G_4} \varepsilon^d_t.$$

We now prove that $(\phi_{\pi,d}, \phi_{\pi,\varepsilon}, \phi_{y,d}, \phi_{y,\varepsilon}) > 0$, a result we use in Proposition 1 in the main text.

Proposition 3. *Under Float AF:* $\phi_{\pi,d}, \phi_{\pi,\varepsilon}, \phi_{y,d}$ *and* $\phi_{y,\varepsilon}$ *are all strictly positive.*

Proof. All deep parameters in the model are positive, and that under Float AF: $\psi < 1-\beta$ and $\phi_\pi < 1$. Start with $\phi_{\pi,d}$. We note that $q < 0$ and thus, by the monotonicity of the square-root function, $\phi_{\pi,d} = -p/2 + \sqrt{p^2/4 - q} > 0$. Now turn to $\phi_{y,d}$ in equation (B.16). We note that the numerator is positive because $\phi_{\pi,d} > 0$ as shown above (remember that $\phi_\pi < 1$). However, the denominator could possibly be negative because $\psi < 1-\beta$. We thus need to show that

$$\varpi\kappa(\varphi + \gamma/\varpi) + \gamma(\beta - 1 + \psi) + \phi_{\pi,d}\zeta\gamma(1-\beta\phi_\pi) > 0. \tag{B.17}$$

We proceed by inserting directly $\phi_{\pi,d}$ into (B.17). Simplifying gives:

$$\begin{aligned} &= \frac{\gamma}{2}\left\{\tilde{\kappa} + \beta - 1 + \sqrt{((\beta - 1 + 2\psi) + \tilde{\kappa})^2 - 4\left(\psi(\beta - 1 + \psi) + \tilde{\kappa}(\beta\phi_\pi - 1 + \psi)\right)}\right\} \\ &= \frac{\gamma}{2}\left\{\tilde{\kappa} + \beta - 1 + \sqrt{(\tilde{\kappa} + \beta - 1)^2 + 4\tilde{\kappa}(1-\beta\phi_\pi)}\right\} \\ &> 0, \end{aligned}$$

where we define $\tilde{\kappa} := \frac{\varpi\kappa}{\gamma}(\varphi + \frac{\gamma}{\varpi})$. $\phi_\pi < 1$ guarantees that $\phi_{y,d} > 0$, again using the monotonicity of the square-root function. Finally, $(\phi_{\pi,\varepsilon}, \phi_{y,\varepsilon}) > 0$ follows immediately from $(1-\psi)\phi_{\pi,\varepsilon} = \phi_{\pi,d}$, and similarly, $(1-\psi)\phi_{y,\varepsilon} = \phi_{y,d}$, as established above. □

Union AF Given the closed-form expressions of the solutions for all target regimes, we now solve for regime Union AF. As in Union PF above, the equilibrium is characterised by the second order difference equation in prices (B.15). Split up $E_t(p_{H,t+1})$ into conditional expectations and evaluate each of them in turn:

$$E_t(p_{H,t+1}|\text{Union PF - Default}) = \phi p_{H,t} \tag{B.18}$$

$$E_t(p_{H,t+1}|\text{Float AF}) = p_{H,t} + \phi_{\pi,d}\hat{d}_t^r \tag{B.19}$$

$$E_t(p_{H,t+1}|\text{Union AF}) = ? \tag{B.20}$$

The third conditional expectation depends on the solution of regime Union AF which we have not yet worked out. First, to obtain an expression for bond yields, use the law of iterated expectations and combine (B.10) and (B.12):

$$i_t = -(1-\mu)(1-\lambda)E_t(e_{t+1}|\text{Float AF}) + (1-\mu)\lambda\zeta^{-1}\delta\hat{d}_t^r. \tag{B.21}$$

Replace $E_t(e_{t+1}|\text{Float AF})$ by combining (B.7) and (B.8):

$$i_t = (1-\mu)(1-\lambda)\left(E_t(p_{H,t+1}|\text{Float AF}) + \frac{\gamma}{\varpi}\phi_{y,d}\hat{d}_t^r\right) + (1-\mu)\lambda\zeta^{-1}\delta\hat{d}_t^r. \tag{B.22}$$

Now insert (B.19) into (B.22) and set $\hat{d}_t^r = \beta^{-1}\left((1-\psi)\hat{d}_{t-1}^r + \zeta(\beta i_t - (p_{H,t} - p_{H,t-1})) + \varepsilon_t^d\right)$ to obtain an expression for the yield i_t purely as a function of today's producer price and the relevant state variables $(p_{H,t-1}, \hat{d}_{t-1}^r, \varepsilon_t^d)$:

$$i_t = \vartheta_1 p_{H,t} + \vartheta_2 p_{H,t-1} + \vartheta_3\hat{d}_{t-1}^r + \vartheta_4\varepsilon_t^d, \tag{B.23}$$

with $\vartheta_1, ..., \vartheta_4$ being coefficient functions of the structural parameters. Plugging back (B.23) into (B.19) yields a similar expression for $E_t(p_{H,t+1}|\text{Float AF})$:

$$E_t(p_{H,t+1}|\text{Float AF}) = \eta_1 p_{H,t} + \eta_2 p_{H,t-1} + \eta_3\hat{d}_{t-1}^r + \eta_4\varepsilon_t^d, \tag{B.24}$$

with, again, $\eta_1, ..., \eta_4$ being coefficient functions of the structural parameters.

We are now in the position to apply the guess-and-verify method. Guess that, while in regime Union AF, producer prices evolve as $p_{H,t} = \phi_p p_{H,t-1} + \phi_d\hat{d}_{t-1}^r + \phi_\varepsilon\varepsilon_t^d$ and solve (B.20):

$$E_t(p_{H,t+1}|\text{Union AF}) = \phi_p p_{H,t} + \frac{\phi_d}{\beta}\left((1-\psi)\hat{d}_{t-1}^r + \zeta(\beta i_t - (p_{H,t} - p_{H,t-1})) + \varepsilon_t^d\right),$$

the third conditional expectation needed to evaluate $E_t(p_{H,t+1})$. Finally, replace i_t by (B.23) and rearrange (B.15) to verify the guess:

$$p_{H,t} = \underbrace{\frac{-(\mu\phi_d\zeta(\beta\vartheta_2+1)+(1-\mu)(1-\lambda)\beta\eta_2+1)}{\mu(\beta\phi_p+\phi_d\zeta(\beta\vartheta_1-1))+(1-\mu)(\beta\lambda\phi+\beta(1-\lambda)\eta_1)-\phi_{aux}}}_{=\phi_p} p_{H,t-1}$$
$$+ \underbrace{\frac{-(\mu\phi_d(1-\psi+\zeta\beta\vartheta_3)+\beta(1-\mu)(1-\lambda)\eta_3)}{\mu(\beta\phi_p+\phi_d\zeta(\beta\vartheta_1-1))+(1-\mu)(\beta\lambda\phi+\beta(1-\lambda)\eta_1)-\phi_{aux}}}_{=\phi_d} \hat{d}^r_{t-1}$$
$$+ \underbrace{\frac{-(\mu\phi_d(\beta\zeta\vartheta_4+1)+(1-\mu)(1-\lambda)\beta\eta_4)}{\mu(\beta\phi_p+\phi_d\zeta(\beta\vartheta_1-1))+(1-\mu)(\beta\lambda\phi+\beta(1-\lambda)\eta_1)-\phi_{aux}}}_{=\phi_\varepsilon} \varepsilon^d_t.$$

Verify the guess first for ϕ_p and ϕ_d to obtain a cubic polynomial in ϕ_d. The polynomial has three real roots, all of which imply explosive paths for the state variables while in Union AF. However, for the calibrated model we verify that at most one of these solution candidates satisfies mean square stability (the root in the interval [0,0.5]). The coefficients ϕ_p and ϕ_ε then follow unambiguously from ϕ_d.

We thus obtain:

$$\underbrace{\begin{bmatrix} p_{H,t} \\ \hat{d}^r_t \end{bmatrix}}_{x_t} = \underbrace{\begin{bmatrix} \phi_p & \phi_d \\ \frac{\zeta(\beta(\vartheta_1\phi_p+\vartheta_2)-(\phi_p-1))}{\beta} & \frac{1-\psi+\zeta(\beta(\vartheta_1\phi_d+\vartheta_3)-\phi_d)}{\beta} \end{bmatrix}}_{=:F_1} \underbrace{\begin{bmatrix} p_{H,t-1} \\ \hat{d}^r_{t-1} \end{bmatrix}}_{x_{t-1}}$$
$$+ \underbrace{\begin{bmatrix} \phi_\varepsilon \\ \frac{\zeta(\beta(\vartheta_1\phi_\varepsilon+\vartheta_4)-\phi_\varepsilon)+1}{\beta} \end{bmatrix}}_{=:G_1} \varepsilon^d_t.$$

C Data Appendix

The frequency of all data used is quarterly. All time series are seasonally adjusted. The data has been obtained in September 2013.

Sovereign bond yields Long-term interest rates for convergence purposes. Spreads are computed as differences in yields. Source: ECB Statistical Data Warehouse.
http://sdw.ecb.europa.eu.

Private sector yields MFI interest rate statistics. Reference area: Greece and Germany. Spreads are computed as differences in yields. Credit and other institutions, balance sheet item: deposits with agreed maturity, total, annualized agreed rate (AAR). Total outstanding amount, non-financial corporations and household sector. Source: ECB Statistical Data Warehouse.
http://sdw.ecb.europa.eu

Debt to GDP Greece Government consolidated gross debt (gov_q_ggdebt), percentage of GDP. Source: Eurostat.
http://epp.eurostat.ec.europa.eu.

Real GDP GDP at market prices, Chain linked volumes, reference year 2005. GDP is detrended using euro zone GDP, computed as differences in relative deviations from 2009.Q3. Source: ECB's Statistical pocket book, Section 11.3.
http://sdw.ecb.europa.eu.

Consumer Price Index Harmonized indices of consumer prices. The CPI is detrended using euro zone CPI inflation, computed as differences in relative deviations from 2009.Q3. Source: Eurostat.
http://epp.eurostat.ec.europa.eu.

Primary deficits This series is computed as the difference between net lending to GDP and interest payments to GDP. Source: Eurostat.
http://epp.eurostat.ec.europa.eu.