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Published Version

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Mavrodimitrakis, C. ORCID: https://orcid.org/0000-0002-7436-9164 (2022) Debt stabilization and financial stability in a monetary union: market versus authority-based preventive solutions. International Journal of Finance & Economics, 27 (2). pp. 2582-2599. ISSN 1099-1158 doi: 10.1002/ijfe.2288 Available at https://centaur.reading.ac.uk/100306/

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Published version at: http://dx.doi.org/10.1002/ijfe.2288
To link to this article DOI: http://dx.doi.org/10.1002/ijfe.2288

Publisher: Wiley

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Received: 15 February 2020 | Revised: 12 September 2020 | Accepted: 16 September 2020

DOI: 10.1002/ijfe.2288

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RESEARCH ARTICLE

Debt stabilization and financial stability in a monetary union: Market versus authority-based preventive solutions

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Abstract

Is a debt-concerned monetary authority desirable? This article deals with the impact of fiscal-monetary policy interactions in a monetary union on country-specific and union-wide debt stabilization, when the authorities act strategically. The focus is on the impact that monetary policy would have on a debt-concerned fiscal authority through the debt constraint and the corresponding interaction with decentralized fiscal policies. It is shown that the fiscal-monetary (overall) policy coordination strategic regime delivers better results than the non-cooperative regime for both the output gap and the outstanding level of debt at the union level. Two further institutional arrangements are investigated and compared: An authority-based preventive procedure, which works through a debt-concerned monetary authority, and a market-based one, which works through financial markets by assuming a risk premium on country-specific nominal interest rates according to the country-specific fiscal stances. The risk premium acts as a form of 'market-based' discipline. Both regimes stand between the decentralized and the centralized setting. The central bank's optimal weight on union-wide debt stabilization is computed when financial markets provide discipline to the fiscal authorities. It is optimal for the social planner to appoint a debt-concerned central banker, if there is a degree of conservatism from the monetary authority, and/or if the social planner cares about union-wide debt stabilization. A higher risk premium parameter enhances the impact of the former on the optimal weight on union-wide debt stabilization, while it reduces the impact of the latter.

KEYWORDS

central bank's preferences, debt stabilization, fiscal/monetary policies, monetary union, strategic interactions

JEL CLASSIFICATION

E62; E63; E65; F45

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1 | INTRODUCTION

This article deals with the issue of debt stabilization and financial stability in a monetary union, referring explicitly to the Economic and Monetary Union (EMU) in Europe. The Eurozone sovereign debt crisis led to a renewed interest in country-specific debt stabilization. In the aftermath of the Great Recession, many member-states of the EMU find themselves with increased deficits and debts that contributed to a lack of access to financial markets in order to cover their needs (Blueschke & Neck, 2011). For some countries, this was also due to substantial efforts to recapitalise the banking sector (Anevlavis, Papavassilopoulos, Engwerda, & van Aarle, 2019). The mainstream view was that the sovereign debt crisis is due to fiscal indiscipline that each country must restore by itself (Wyplosz, 2014). The result was the introduction of the fiscal compact (FC) in 2012, which made the stability and growth pact (SGP) more stringent and rigid, mainly through the requirement to constitutionalize rules on government deficits and debts (Panico & Purificato, 2013). De Grauwe and Ji (2014) criticize this view by stretching that at the creation of the EMU there was a structural change in the nature of the debt of the member-states. In particular, by joining the EMU, member-states have to issue debt in a currency over which they have no control, an issue that fundamentally changes their budget constraints. To quote the authors, "...it is surprising that this fundamental change has played almost no role in the theoretical discussions of fiscal policies in a monetary union" (De Grauwe & Ji, 2014, p. 349).

This article deals with the impact of fiscal-monetary policy interactions in a monetary union on country-specific and union-wide debt stabilization. A debt accumulation equation as a (non-binding) government budget constraint is assumed in order to consider the design of stabilization policies. The focus is on the impact that monetary policy would have on a debt-concerned fiscal authority through the debt constraint and the corresponding interaction with decentralized fiscal policies. The strategic regime of fiscal-monetary (overall) policy coordination is also investigated, along with the impact of alternative central bank's preferences towards union-wide debt stabilization on the policy mix. The central bank's optimal weight on union-wide debt stabilization is also computed. Then, a risk premium on country-specific nominal interest rates according to the country-specific fiscal stances is assumed, in order to investigate the outcome for the policy mix and for debt stabilization. The risk premium acts as a form of 'market-based' discipline, since prudent policy-makers would seek to avoid high indebtedness (Anevlavis et al., 2019). Thus, the idea is to compare the two preventive procedures: (a) the authority-based one, which works through a debt-concerned monetary authority, and (b) the market-based one through financial markets. Then, the central bank's optimal weight on union-wide debt stabilization is again computed when financial markets provide discipline to the fiscal authorities.

Is it optimal for the social planner of the monetary union to appoint a debt-concerned central banker when the fiscal authorities are debt-concerned (so, debt-constrained)? What happens when the financial markets are preemptive? These are the questions that this article tries to answer. Following Blanchard (2012), one of the main lessons of the Great Recession regarding the conduct of monetary policy was that even with stable inflation and a stable output gap, things might not going well behind the macroeconomic scene. Tensions can build up in the financial sector and financial instability eventually translates into major problems in terms of output and activity. Put differently, price stability does not in itself ensure financial stability (Hughes Hallett, Libich, & Stehlık, 2011). Thus, the list of central bank's targets must now include financial stability as well as macroeconomic stability. The debate today is whether monetary policy should deal with macroeconomic stability and macro-prudential tools with financial stability, that is, whether those activities can be kept separate, even be pursued by different authorities, or we need to think about monetary policy in a broader sense as having many targets and many instruments, where all interact with one another. With respect to the monetary authority, this corresponds to the leaning versus cleaning debate. That is, should the central bank react to potential asset-price bubbles, or clean up after the bubble has been burst? We add to this debate by assuming that debt stabilization assumes financial stability.

The literature combines static models of this kind, two-period models, as well as models based on differential games, which rely on numerical simulations (Blueschke & Neck, 2011; Neck & Blueschke, 2014). Van Aarle, Bovenberg, and Raith (1997) examine the effect of a monetary union, especially the existence of a common central bank, on the evolution of government debt in a dynamic model. Beetsma and Bovenberg (1999, 2003, 2005) examine different aspects of debt accumulation in a monetary union with commitment problems in a series of papers. Di Bartolomeo and Di Gioacchino (2008) focus on the long-run effects of institutional arrangements (sequence of moves) on public debt dynamics. Hughes Hallett (2008a, 2008b) creates fiscal pre-commitment by allowing fiscal policy to achieve certain long-run objectives, such as low debt, better public services, and/or social equality, whereas short-run stabilization is left to

automatic stabilizers. The government budget constraint corresponds to a debt target, whereas the fiscal authority's loss function differs from the literature in that it includes a debt target instead of the fiscal stance. Foresti (2015) also considers debt-concerned fiscal authorities. The author examines the policy-mix problem in a two-country monetary union when the national fiscal authorities need to satisfy a debt constraint. Hughes Hallett et al. (2011) point out that excessive public debt can cause financial instability. The authors explore to what extent the fiscal/monetary authorities should respond to developments that can cause financial instability in a closed-economy setting.[1] Albulescu and Oros (2014) analyse the impact of fiscal-monetary policy interactions on a financial stability index in a monetary union under demand shocks when the common central bank follows an interest rate smoothing approach. The authors also consider fiscal authorities' cooperation and authorities' preferences for the financial stability index, while they ex-post compare alternative institutional arrangements at the union level. Blueschke and Neck (2011) extend Neck and Behrens (2009) by introducing an asymmetry on the initial levels of debt between the core member-state and the periphery country (low vs. high, respectively). The focus is on how a negative demand shock affects the main macroeconomic variables in the union under different policy arrangements, namely a passive scenario, a non-cooperative one and a cooperative one. This work is further extended in Neck and Blueschke (2014) to consider the impact of a possible haircut for the monetary union as a whole, where the haircut is presented as an exogenous debt reduction for the periphery bloc.[2]

The structure of the article is as follows: Section 2 presents the model and relates it to the rest of the literature; Section 3 solves for the two cases of no coordination and coordination, while it also provides a comparison; Section 4 explores the authority-based preventive solution, namely the case of a debt-concerned central banker; Section 5 analyses the market-based preventive solution, captured by the existence of a risk premium, while it also compares the two preventive solutions; in Section 6, the case of a debt-concerned central banker is explored in the presence of a risk premium, while the optimal degree of a debt-concerned central banker is computed. Finally, Section 7 concludes the article.

2 | THE MODEL

We use a standard static two-country reduced-form monetary union model based on the (New) Keynesian paradigm. Models of this kind have been used in many papers in the literature on strategic fiscal-monetary policy interactions in monetary unions (Andersen, 2008; Foresti, 2015, 2018; Hughes Hallett & Mavrodimitrakis, 2019; Lambertini & Rovelli, 2004; Uhlig, 2003). The choice to use a reduced-form model is deliberate in providing closed-form analytical solutions in order to clarify the mechanisms that drive the results.[3] We consider a monetary union consisted of two countries, namely j and k. The non-policy block of equations for each country is constituted by an aggregate demand (AD) and a Phillips curve (PC) equation. Microfoundations are well-known and are provided by Beetsma and Jensen (2005), Benigno (2015), and Gali and Monacelli (2008). In country j, for example, these equations are specified as:

$$y_j = -\delta_r\left(i - \pi_j^e - \bar{r}_j\right) + \delta_g g_j + u_j, \tag{1}$$

$$\pi_j = \pi_j^e + \omega y_j - \epsilon_j, \tag{2}$$

and the same holds for country k. All the variables represent log-deviations from equilibrium values, apart from the decimal (common) nominal interest rate, i. The variables π and y represent the inflation rate and the output gap, respectively, while g represents fiscal policy, captured by the overall fiscal stance. The variable $\bar{r}_j$ represents the equilibrium real interest rate, which for simplicity we set equal to zero for both countries, while π_j^e is the (rationally) expected inflation rate. Regarding the parameters' sign, they are all positive. The parameter δ_r captures the real interest sensitivity of aggregate demand and δ_g captures the fiscal multiplier, that is, the effectiveness of fiscal policy, while ω is the slope of the Phillips curve, capturing nominal (price/wage) rigidities in the economy. u_j and ϵ_j are independently and identically distributed (i.i.d.) demand and supply shocks, respectively. We assume that they both are pure and uncorrelated, with zero means and known variances. The two countries can differ in size. This means that we consider two asymmetric countries, where each country will have a weight in the monetary union average given by z_j, $z_k \in (0,1)$; so, $z_j + z_k = 1$. Averaging over countries gives the union-wide structural equations:

$$y = -\delta_r(i - \pi^e) + \delta_g g + u, \tag{3}$$

$$\pi = \pi^e + \omega y - \epsilon, \tag{4}$$

where for any variable x it holds that $x = z_j x_j + z_k x_k$.

We do not distinguish among alternative fiscal policy instruments, but we instead use the overall fiscal stance as the unique fiscal policy instrument. Then, a positive

fiscal stance creates a positive output gap, which increases inflation. However, different fiscal policy instruments might also have an impact on potential output, together with their impact on aggregate demand; for example, taxes on sales or productivity-enhancing public investment. Thus, the overall impact on the output gap might be ambiguous. We, however, abstract from this reasoning, assuming that the demand-side effects of fiscal policies prevail, since we focus on short-run stabilization policies.[4] This can be further justified by the static Keynesian framework adopted, and follows most of the literature in strategic fiscal-monetary policy interactions.[5]

The monetary authority and the fiscal authorities' loss functions take the typical quadratic form:

$$L_M = \frac{1}{2}\left(\pi^2 + \alpha_M y^2\right), \tag{5}$$

$$L_{F_j} = \frac{1}{2}\left(b_j^2 + \alpha_F y_j^2\right), \tag{6}$$

where b_j corresponds to the country-specific outstanding level of (newly issued) debt, defined as:

$$b_j = \left(1 + i - \pi_j^e\right) b_0 + g_j, \tag{7}$$

where b_0 is the already accumulated level of debt; that is, the amount of debt carried over from the previous period. We assume the same level of already accumulated debt, b_0, for both member-states. We further assume that all the authorities have complete control over their own policy instrument (g_j, g_k, i) and that a quadratic loss function is a good approximation of their preferences over some variables (Dixit & Lambertini, 2003). All the authorities target long-run equilibrium values of concerned variables. In particular, we assume that the common central bank is concerned with the output gap and the inflation rate in the union (Equation (5)), whereas the two national fiscal authorities are concerned with the output gap and the outstanding level of debt for their own country (Equation (6)), and they share identical preferences. To simplify matters, a debt target equal to zero is assumed. The relative weights on output-gap stabilization are α_M and α_F for the monetary and the fiscal authorities, respectively.

The monetary authority's loss function (Equation (5)) is quite standard and captures the case of a flexible inflation targeting central bank, which, according to some authors, best fits the actual workings of the ECB (Andersen, 2008). This specification is also assumed by Foresti (2015), Hughes Hallett and Mavrodimitrakis (2019), and Uhlig (2003), and it can capture secondary objectives (so long as $\alpha_M < 1.0$).[6] On the contrary, the national fiscal authorities' loss function (Equation (6)) is less common in the literature and follows Foresti (2015). The standard case is the one that the national fiscal authorities are concerned with country-specific fiscal stance stabilization, along with output-gap stabilization, as countries in EMU are constrained by the SGP (Andersen, 2008; Hughes Hallett & Mavrodimitrakis, 2019; Lambertini & Rovelli, 2004; Uhlig, 2003). Public deficits ceilings are imposed because of their impact on public debt. However, Equation (6) shows that the two national fiscal authorities are directly concerned with their outstanding level of debt. In general, there are issues that refer to intertemporal solvency regarding the repayment of debt and the taxes that this may produce in the future (Foresti, 2015). Debt ceilings, instead of deficit ones, could achieve public debt sustainability with lower costs in terms of short-run flexibility (Debrun, 2000). Debt sustainability requires convergence to a constant debt ratio over time, since, in a dynamic setting, a higher outstanding level of debt restricts future ability of governments to counteract shocks. Equation (6) can be also justified on empirical terms; both Melitz (1997) and Wyplosz (2005) find that fiscal authorities respond in a stabilizing manner to debt-output ratios, while Bénétrix and Lane (2013) show that the positive association between the debt level and the fiscal balance was strengthened in the post-Maastricht period. Debt targets were officially introduced in the Eurozone with the FC in 2012, according to which governments are required to reduce their debt ratios its year by one twentieth of their current debt over 60%.

There are studies in the literature on strategic policy interactions that assume debt-concerned fiscal authorities both in a closed-economy setting (Hughes Hallett & Weymark, 2007) and in monetary unions (Foresti, 2015; Hughes Hallett, 2008b; Hughes Hallett & Weymark, 2006). Hughes Hallett (2008b) provides theoretical justification for debt rules as a force of fiscal pre-commitment, by allowing fiscal policy to achieve certain long-run objectives, whereas short-run stabilization is left to automatic stabilizers; hence fiscal policy in the form of government spending is procyclical. Following this line of thought, Equation (6) combines short-run with long-run objectives for the national fiscal authorities. Kirsanova, Stehn, and Vines (2005) assume an exogenous fiscal rule, similar to a standard Taylor rule for monetary policy, in which fiscal policy reacts both to the output gap and to the outstanding level of debt. Finally, debt-concerned fiscal authorities are assumed in the dynamic(differential)-game literature (Blueschke & Neck, 2011; Neck & Behrens, 2009; Neck & Blueschke, 2014, 2016).[7] Those papers assume that the national fiscal authorities are concerned with country-specific output gap, inflation, fiscal stance, and debt stabilization.

Equation (7) defines a short-run (one-period) government budget constraint in the form of a debt

accumulation equation. It can be found in Beetsma and Bovenberg (1999), which is also formally derived,[8] while it is also incorporated by Blueschke and Neck (2011), Della Posta (2018), Foresti (2015, 2018), and van Aarle (2013). Equation (7) clearly states that the outstanding level of debt equals the fiscal stance, g_j, plus the already accumulated level of debt, b_0, plus the debt service real cost, $\left(i-\pi_j^e\right)b_0$ (Foresti, 2015). A possible rise in the country-specific fiscal stance increases the country-specific outstanding level of debt, which means that we deal with debt-financed expansionary fiscal policies. Finally, we assume no seigniorage revenues. Equation (7) clearly shows that an expansionary monetary policy can reduce the real value of the outstanding level of debt. Foresti (2015) explores the decentralized case under differing already accumulated levels of debt. The author's main result is that member-states with an already accumulated level of debt higher than the union-wide one cannot attain the target, even in the absence of demand/supply shocks.

Excessive public debt can cause financial instability (Hughes Hallett et al., 2011). Sovereign debt affects financial stability, for example, via government bonds held by banks. In a reduced-form model similar to ours, Hughes Hallett et al. (2011) assume that the asset growth gap is positively affected by fiscal policy and negatively affected by monetary policy. This means that an expansionary fiscal policy and/or a restrictive monetary policy induces financial instability. The authors embrace a medium-run analysis. They explore the authorities' degree of pro-activism to financial instability in a closed economy. They find that financial instability should be mitigated by the fiscal authority alone in some circumstances, and jointly by both authorities in some others. Albulescu and Oros (2014) assume a union-wide financial stability index that is negatively affected by both fiscal and monetary policies. This again means that an expansionary fiscal policy increases this index, hence generating more instability, while an expansionary monetary policy reduces this index, producing less instability. Both of these characteristics are captured by Equation (7), hence linking debt stabilization with financial stability. Averaging over countries gives the union-wide debt accumulation equation, as:

$$b=(1+i-\pi^e)b_0+g, \tag{8}$$

where b corresponds to the union-wide (average) outstanding level of debt.

We are also interested in the case of fiscal-monetary (overall) policy coordination, in which all the authorities cooperate with each other in choosing their means in order to achieve their joint objectives. The joint loss function is given by:

$$\begin{aligned} L_C &= L_M + z_j L_{F_j} + z_k L_{F_k} \\ &= \frac{1}{2}\left[\pi^2 + z_j b_j^2 + z_k b_k^2 + \alpha_M y^2 + \alpha_F\left(z_j y_j^2 + z_k y_k^2\right)\right], \end{aligned} \tag{9}$$

where '*C*' stands for '*Coordination*'. We follow Blueschke and Neck (2011), Lambertini and Rovelli (2004), and Neck and Blueschke (2014) by assuming that overall policy coordination is the result of the minimization of a joint loss function that includes all authorities' loss functions in a straightforward additive way, namely Equations (5) and (6), where we also follow Andersen (2008) by adding the mean of the fiscal authorities' loss functions. Naturally, this joint loss function includes both union-wide and country-specific variables, while the spill-over effect of the common monetary policy will be fully internalized. Overall policy coordination requires that the authorities minimize Equation (9) subject to Equations (1)–(4), (7), and (8), and to the average relations.

The model assumes a simultaneous-move game among the authorities. The time structure of the game is as follows: first, the private sector forms expectations about future inflation rationally; second, demand and supply shocks are realized; then, the policy authorities choose their instrument of command to minimize their loss functions. The two national fiscal authorities choose their corresponding fiscal stances, g_j and g_k, simultaneously with each other and with the common central bank, which sets the common nominal interest rate for the monetary union. The equilibrium of this game corresponds to a Cournot-Nash equilibrium. Since we deal with discretionary policies and all the authorities target equilibrium values of concerned variables, policies are time-consistent; it follows that $\pi^e=\pi_j^e=0$ (Andersen, 2008; Uhlig, 2003). Finally, the country-size asymmetry assumption plays no role in this model; that is, it delivers exactly the same results with the symmetric case of $z_j = z_k = 0.5$, since we have assumed (a) no interconnections between the two member-states apart from the common nominal interest rate, and (b) no leadership regimes between the fiscal authorities and the monetary authority.

3 | ALTERNATIVE INSTITUTIONAL ARRANGEMENTS

We present two alternative institutional arrangements for the monetary union, regarding policy coordination. We begin with the decentralized case of no coordination between the monetary authority and the two national

fiscal authorities, we proceed with the case of overall policy coordination, and, finally, we compare and contrast the two cases.

3.1 | The decentralized case

The discretionary setting requires that all the authorities set policy simultaneously, just after the realization of demand and supply shocks. Starting with the monetary authority, its problem is quite simple; with all the authorities targeting long-run equilibrium values and the two policy instruments being perfect substitutes in the stabilization process, the common monetary policy succeeds in determining union-wide inflation and output gap independently of country-specific fiscal policies. In particular, the monetary authority chooses the common nominal interest rate to minimize its loss function, namely Equation (5), subject to the union-wide non-policy block of equations, namely Equations (3) and (4). Moreover, it takes for granted the fiscal stances of both national fiscal authorities. The monetary rule is defined as:

$$y = -\frac{1}{\alpha_M}\frac{\partial \pi}{\partial y}\pi = -\frac{\omega}{\alpha_M}\pi. \tag{10}$$

Equation (10) represents the standard trade-off between output gap and inflation stabilization, independently of fiscal policy. Combining the monetary rule, meaning Equation (10), with the union-wide PC equation, namely Equation (4), we get the union-wide equilibrium solutions for the output gap and the inflation rate:

$$y = \frac{\omega}{\omega^2 + \alpha_M}\epsilon, \tag{11}$$

$$\pi = -\frac{\alpha_M}{\omega^2 + \alpha_M}\epsilon. \tag{12}$$

Equations (11) and (12) clearly show that the monetary authority succeeds in fully stabilizing union-wide demand shocks, while it partially stabilizes supply shocks, depending on its weight on output-gap stabilization.

Each national fiscal authority, let country *j*'s, minimize its loss function, Equation (6), subject to its country-specific aggregate demand equation and its budget constraint (debt accumulation equation), that is, Equations (1) and (7), respectively, while it takes for granted both the fiscal stance of the other fiscal authority and the common nominal interest rate that emerges from the monetary authority's problem.[9] The first-order condition delivers the fiscal rule for country *j*'s fiscal authority that shows the way it reacts to a change in its own output gap, as:

$$b_j = -\alpha_F \frac{\partial y_j}{\partial g_j} y_j = -\alpha_F \delta_g y_j. \tag{13}$$

Equation (13) shows the emerging trade-off between the country-specific output gap and the outstanding level of debt: each national fiscal authority reacts to a negative output gap by raising its outstanding level of debt through an expansionary fiscal policy. It also represents a trade-off between short and long-(or medium)-run objectives. Because of symmetry, Equation (13) holds for both member-states. By averaging, we get:

$$b = -\alpha_F \delta_g y, \tag{14}$$

which corresponds to the union-wide fiscal rule.

A straightforward algebra provides us with all the union-wide and country-specific macroeconomic variables at equilibrium. By incorporating the union-wide equilibrium output gap, namely Equation (11), to the union-wide fiscal rule, namely Equation (14), we get the union-wide outstanding level of debt at equilibrium:

$$b = -\frac{\alpha_F \delta_g \omega}{\omega^2 + \alpha_M}\epsilon. \tag{15}$$

Equation (15) clearly states that the union-wide outstanding level of debt is only affected by supply shocks. Under either no shocks or demand shocks, the union-wide outstanding level of debt is fully stabilized (equal to its target) by the use of both policy instruments, meaning the common nominal interest rate and the union-wide fiscal stance.

In order to compute both policy instruments at equilibrium, we incorporate the union-wide outstanding level of debt (Equation (15)) to the union-wide debt accumulation Equation (8) and we solve this equation together with the union-wide aggregate demand equation, namely Equation (3), after we incorporate the union-wide equilibrium output gap, namely Equation (11). We end up with:

$$i = \frac{1}{\delta_r + \delta_g b_0} \times \left[-\delta_g b_0 + u - \left(1 + \alpha_F \delta_g^2\right) \frac{\omega}{\omega^2 + \alpha_M}\epsilon \right], \tag{16}$$

$$g = -\frac{1}{\delta_r + \delta_g b_0} \times \left[\left(\delta_r + u - \frac{\omega}{\omega^2 + \alpha_M}\epsilon \right) b_0 + \alpha_F \delta_g \delta_r \frac{\omega}{\omega^2 + \alpha_M}\epsilon \right]. \tag{17}$$

In the absence of shocks, monetary policy is expansionary, while fiscal policy is contractionary, which means that the two policy instruments are perfect substitutes; in this case, they both react to the each other. The common

nominal interest rate reacts explicitly to union-wide demand shocks, while this reaction weakens with the already accumulated level of debt (see Equation (16)). Following Equation (17), positive demand shocks and negative supply shocks enhance union-wide fiscal policy's restrictive reaction, as they both induce a restrictive monetary policy that would expand the outstanding level of debt. The union-wide fiscal stance reacts to union-wide demand shocks only through its reaction to the already accumulated level of debt, since the latter is actually the impact of monetary policy on the union-wide outstanding level of debt.

Regarding supply shocks, the union-wide fiscal policy ends up either counter-cyclical or pro-cyclical, with high levels of the already accumulated debt working in favour of pro-cyclicality. A positive union-wide supply shock that reduces union-wide inflation leads to an expansionary monetary policy, which induces an increase in the country-specific aggregate demand and a reduction in the country-specific outstanding level of debt. Thus, the national fiscal authorities would like to reduce their fiscal stance in response to the former effect and to expand it to the latter one, according to the trade-off described by their fiscal rules (Equation (13)). Consequently, the result is ambiguous, depending on the already accumulated level of debt. On the contrary, monetary policy always ends up pro-cyclical; for example, positive supply shocks reduce the inflation rate, inducing a reduction to the nominal interest rate. Moreover, the already accumulated level of debt induces a reduction to country-specific fiscal stance, which reduces country-specific output gap, which reduces the inflation rate. Thus, the common central bank decreases the common nominal interest rate as a reaction to fiscal policy.

The relative output gap, that is, the difference between the two countries', is computed by incorporating the country-specific fiscal rule, Equation (13), and the solution for the common nominal interest rate at equilibrium, Equation (16), to both the country-specific aggregate demand Equation (1) and the country-specific budget constraint, namely Equation (7), and solving together. We end up with:

$$y_j - y_k = \frac{1}{1+\alpha_F\delta_g^2} \times \left(u_j - u_k\right). \tag{18}$$

Equation (18) shows that the country-specific output gaps differ if there are demand shock asymmetries. The country-specific output gap is not affected by the level of already accumulated debt, b_0. This means that the inclusion of the government budget constraint for the national fiscal authorities, meaning Equation (7), and the subsequent national fiscal authorities' concern for stabilizing the country-specific outstanding level of debt instead of the fiscal stance, do not alter country-specific output gap at equilibrium. The relative fiscal stances and outstanding levels of debt at equilibrium, can be found to be:

$$g_j - g_k = b_j - b_k = -\frac{\alpha_F\delta_g}{1+\alpha_F\delta_g^2} \times \left(u_j - u_k\right). \tag{19}$$

Since there is a common nominal interest rate and the already accumulated level of debt for both countries is the same, the relative fiscal stance is equal to the relative outstanding level of debt, where the latter can be computed from the subtraction of the two country-specific fiscal rules, using the equilibrium solution for the relative output gap, too, namely Equation (18).

Following Equation (19), all country-specific equilibrium variables differ under demand shock asymmetries. Foresti (2015) considers different already accumulated levels of debt and shows that the country-specific outstanding level of debt cannot be fully stabilized, even in the absence of shocks. We can easily derive an equilibrium solution for country-specific fiscal stance after combining Equations (17) and (19) together with the union-wide relations. Then, the country-specific fiscal stance reacts counter-cyclically to union-wide demand shocks because of the existence of the already accumulated level of debt and also to demand shock asymmetries. The national fiscal authorities react either counter-cyclically or pro-cyclically to a foreign shock, depending on their own trade-off between debt and output-gap stabilization, as the result of the monetary reaction ($b_0 - \alpha_F\delta_g\delta_r$). Regarding supply shocks, the existence of the already accumulated level of debt makes the country-specific fiscal stance be either positive or negative. A possible negative supply shock that increases the union-wide inflation rate induces a restrictive monetary reaction that increases the country-specific outstanding level of debt. Thus, the national fiscal authorities restrict their fiscal stance in order to stabilize their outstanding level of debt, while they expand it to counteract the negative impact of a restrictive monetary policy to their own output gap. Thus, the overall result is ambiguous.

We have already discussed the impact of the debt-concerned fiscal authorities on the macroeconomic policy mix, relative to the standard case of fiscal stance stabilization, where the latter case can be obtained after setting $b_0 = 0$ to all the equilibrium solutions. Moreover, we would like to compute the country-specific and union-wide debt for the standard case in the literature. We can get the common nominal interest rate and the union-wide fiscal stance from Equations (16)

and (17) for $b_0 = 0$, while for the country-specific fiscal stance we use Equation (19). Combining those three equations with the country-specific and union-wide debt accumulation Equations (7) and (8), we get:

$$b = b_0 + \frac{1}{\delta_r} \times \left\{ b_0 u - \left[b_0 + \alpha_F \delta_g \left(\delta_r + \delta_g b_0 \right) \right] \frac{\omega}{\omega^2 + \alpha_M} \epsilon \right\}, \tag{20}$$

where for the country-specific solution we use Equation (19). By comparing Equation (20) with Equation (15), we can easily see that both demand shocks and the already accumulated level of debt cannot be fully stabilized under the standard case in the literature where fiscal authorities care about country-specific fiscal stance stabilization instead of debt stabilization, while supply shocks are also less stabilized.

3.2 | The overall policy coordination regime

We consider the case of fiscal-monetary (overall) policy coordination. The monetary authority and the two national fiscal authorities cooperate with one another in order to coordinate their macroeconomic policies. They all set policy according to the minimization of Equation (9). The monetary policy is implemented by taking into account its impact on the country-specific outstanding level of debt, while the country-specific fiscal policy takes into account its impact on union-wide inflation. The first-order conditions are defined as:

$$\begin{aligned} &\frac{\partial y}{\partial g} \times \left(\frac{\partial \pi}{\partial y} \pi + \alpha_M y + \alpha_F y_j \right) + b_j = 0 \\ &\Rightarrow \omega \delta_g \pi + \alpha_M \delta_g y + \alpha_F \delta_g y_j + b_j = 0, \end{aligned} \tag{21}$$

$$\frac{\partial y}{\partial i} \times \left[\frac{\partial \pi}{\partial y} \pi + (\alpha_F + \alpha_M) y \right] + \frac{\partial b}{\partial i} b = 0 \Rightarrow b_0 b = \delta_r (\omega \pi + \alpha y), \tag{22}$$

where $\alpha = \alpha_F + \alpha_M$ defines the overall weight that the monetary authority and the national fiscal authorities place on the stabilization of union-wide and country-specific output gap, respectively. Equation (22) says that an increase in union-wide inflation and/or output gap leads to an increase in the union-wide outstanding level of debt caused by a contractionary monetary policy; namely, an increase in the common nominal interest rate. Equation (21) holds for both member-states. After averaging, we get:

$$b = -\delta_g (\omega \pi + \alpha y). \tag{23}$$

Equation (23) shows that the union-wide outstanding level of debt decreases when the union-wide inflation rate and/or the output gap increases, since this induces a contractionary fiscal policy; hence a decrease in the fiscal stance.

Solving Equations (22) and (23) together with the union-wide PC equation (Equation (4)), we end up with the equilibrium solutions for the union-wide inflation rate, the output gap, and the outstanding level of debt, as:

$$y = \frac{\omega}{\omega^2 + \alpha} \epsilon, \tag{24}$$

$$\pi = -\frac{\alpha}{\omega^2 + \alpha} \epsilon, \tag{25}$$

$$b = 0. \tag{26}$$

Similar to the decentralized case, Equations (24) and (25) clearly state that demand shocks are fully stabilized at the union level with regard to union-wide output gap and inflation rate, whereas supply shocks are only partially stabilized. The union-wide outstanding level of debt is fully stabilized, as Equation (26) shows. In order to grasp this result, we report the equilibrium solutions for the two policy instruments, meaning the common nominal interest rate and the union-wide fiscal stance. We substitute the solution for the union-wide outstanding level of debt, meaning Equation (26), to the union-wide debt accumulation Equation (8) and we solve it together with the union-wide aggregate demand equation, namely Equation (3), after we substitute for the union-wide output gap (Equation (24)). We end up with:

$$i = \frac{1}{\delta_r + \delta_g b_0} \times \left(-\delta_g b_0 + u - \frac{\omega}{\omega^2 + \alpha_M} \epsilon \right), \tag{27}$$

$$g = -\frac{b_0}{\delta_r + \delta_g b_0} \times \left(\delta_r + u - \frac{\omega}{\omega^2 + \alpha_M} \epsilon \right). \tag{28}$$

Equations (27) and (28) reveal that the level of the already accumulated debt, b_0, is stabilized by the use of both policy instruments, whereas for union-wide demand and supply shocks, the two policy instruments are perfect substitutes. The difference with the decentralized regime defined by Equations (16) and (17) is that here the union-wide fiscal policy does not directly react to union-wide supply shocks, but only through the already accumulated level of debt. This means that it fully offsets the impact of the common

nominal interest rate on the outstanding level of debt, as with no already accumulated level of debt, union-wide fiscal policy remains passive.

The remaining relative equilibrium solutions are exactly the same as before. Following Equation (19), the country-specific outstanding level of debt differs from target only under demand shock asymmetries, since at the union level it is fully stabilized. Regarding fiscal cyclicality, following again Equation (19) together with Equation (28), the national fiscal authorities react pro-cyclically to supply shocks. To counter a negative supply shock, the common central bank induces a restrictive reaction that increases the country-specific outstanding level of debt in the decentralized case. Thus, the national fiscal authorities restrict their fiscal stance in order to stabilize their own level of debt, while they expand it to counteract the negative impact of the restrictive monetary policy to the country-specific output gap. It is this latter effect that is internalized in the overall policy coordination regime through the monetary reaction, leaving the former effect alone.

3.3 | A comparison of the previous policy regimes

A straightforward comparison of the two policy regimes according to macroeconomic stabilization shows that fiscal-monetary (overall) policy coordination delivers better results for all the macroeconomic variables under supply shocks, apart from the union-wide inflation rate that is less volatile in the decentralized case, and both the country-specific and union-wide fiscal stance, which are ambiguous. By better results we mean that the macroeconomic variables are less volatile in a specific institutional arrangement (policy regime). For demand shocks, the two cases (with or without coordination) are exactly the same for all the macroeconomic variables. In particular, for supply shocks, both the union-wide and country-specific outstanding level of debt are fully stabilized in the overall policy coordination regime, whereas both the union-wide and country-specific output gap are less volatile, comparing with the standard decentralized case. This means that the fiscal/monetary reaction to shocks have no implications for debt stabilization under overall policy coordination. Turning now to the welfare implications of the alternative policy regimes, under supply shocks, the national fiscal authorities are better off in the fiscal-monetary policy coordination regime, while the common central bank prefers the decentralized regime.[10]

4 | THE AUTHORITY-BASED PREVENTIVE SOLUTION

We saw in the previous section that all the macroeconomic variables, apart from the union-wide inflation rate, end up less volatile in the overall policy coordination regime for supply shocks, and especially the union-wide outstanding level of debt, which is fully stabilized. We thus consider two alternative institutional arrangements that might approximate the overall policy coordination regime under the standard decentralized case. In this section, we consider the case that the monetary authority is also concerned about union-wide debt stabilization. In the next section, we deal with the case that financial markets are preemptive.

We assume a 'debt-concerned' monetary authority. It can be found in the literature in Hughes Hallett (2008a, 2008b) and Neck and Behrens (2009), and also in debt-stabilization games (Di Bartolomeo & Di Gioacchino, 2008; Tabellini, 1986; van Aarle et al., 1997). Hughes Hallet's papers present a monetary authority that is forced to take into account the government's objectives as a measure of independence, following Beetsma and Uhlig (1999), in which the government has a debt target. Neck and Behrens (2009) utilize a dynamic-game analysis, relying on numerical solutions. In what follows, the monetary authority would have an explicit concern for debt stabilization at the union level. We solve again the decentralized case by replacing Equation (5) with the following one:

$$L_M = \frac{1}{2}\left(\pi^2 + \alpha_M y^2 + \gamma_M b^2\right), \tag{29}$$

where γ_M corresponds to the weight that the common central bank places on union-wide debt stabilization, relative to union-wide inflation stabilization. The monetary rule will be different than before, since the monetary authority takes into account its policy's impact on the outstanding level of debt at the union level. The monetary authority minimizes its loss function now given by Equation (29), subject to the union-wide descriptive equations, namely, Equations (3) and (4). The first-order condition for this problem reads:

$$\frac{\partial y}{\partial i} \times \left(\frac{\partial \pi}{\partial y}\pi + \alpha_M y\right) + \gamma_M \frac{\partial b}{\partial i} b = 0. \tag{30}$$

Equation (30) looks like Equation (22), which is the corresponding one for the overall policy coordination regime. However, the country-specific fiscal rule in this case is exactly the same with the one from the standard decentralized case, namely, Equation (13), which is quite

different to the one from the overall policy coordination regime, given by Equation (21) (and quite different to Equation (23) that defines the union-wide fiscal rule).

Combining Equation (30) with the union-wide fiscal rule, namely Equation (14), we get the monetary rule:

$$y = -\frac{\omega\delta_r}{\alpha_M\delta_r + \gamma_M b_0 \alpha_F \delta_g}\pi. \tag{31}$$

Following the monetary rule (Equation (31)), the monetary reaction to a change in union-wide inflation is now milder, while it becomes even milder with the already accumulated level of debt, which actually defines the impact of monetary policy on the outstanding level of debt, and with the fiscal reaction parameter, given by $\alpha_F\delta_g$. Overall, the results are similar to the decentralized case, while the reactions to supply shocks are now milder; for either demand or no shocks, the results are equivalent to the benchmark case's. A debt-concerned central banker delivers less volatile macroeconomic variables under supply shocks, apart from for the union-wide inflation rate, while the national fiscal authorities are better off. The equilibrium solutions for the main macroeconomic variables and for the policy instruments are given in section 'Appendix to Section 4', along with the macroeconomic stabilization and welfare comparisons to the standard decentralized case.

In what follows, we would like to compute the optimal value of the weight that the common central bank places on union-wide debt stabilization, γ_M, following the methodology of Rogoff (1985). In particular, we assume that this is chosen at stage 0 by the social planner, before the realization of shocks, according to the minimization of the expected value of their loss function, subject to the equilibrium solutions for the union-wide output gap, the inflation rate and the outstanding level of debt in the decentralized case.[11] Thus, we need to assume a social loss function for the monetary union as a whole. The literature usually assumes that this function includes union-wide inflation, output gap, and fiscal stance (Andersen, 2008; Beetsma & Bovenberg, 1998; Hughes Hallett & Mavrodimitrakis, 2019). On the contrary, since we incorporate a debt accumulation equation and the national fiscal authorities are concerned with country-specific debt stabilization, we replace the union-wide fiscal stance with the union-wide outstanding level of debt. Thus, we consider the following social loss function:

$$L_S = \frac{1}{2}\left(\pi^2 + \alpha_S y^2 + \gamma_S b^2\right), \tag{32}$$

where α_S and γ_S are the weights that the social planner places on union-wide output gap and debt stabilization, respectively. In the EMU's context, this loss function can be thought of representing the preferences of the European Council (Hughes Hallett & Mavrodimitrakis, 2019).

By minimizing the expected value of Equation (22) with respect to γ_M, the optimal degree of a debt-concerned central banker can be found to be:

$$\gamma_M = \frac{\delta_r}{b_0} \times \left[\frac{1}{\alpha_F\delta_g}(\alpha_S - \alpha_M) + \alpha_F\delta_g\gamma_S\right]. \tag{33}$$

Equation (33) clearly shows that a debt-concerned central banker is desirable (i.e., optimal) as long as (a) the social planner differs from the monetary authority in their weights towards union-wide output-gap stabilization, $\alpha_S - \alpha_M$, and (b) the social planner also cares about union-wide debt stabilization, γ_S. The fiscal reaction parameter, given by $\alpha_F\delta_g$, decreases the former effect and increases the latter. The fiscal reaction parameter shows how the national fiscal authorities react to a change in the country-specific output gap. A higher fiscal reaction parameter means that the national fiscal authorities react more to changes in the country-specific output gap, which leads to larger changes to the outstanding level of debt in the monetary union. As long as the social planner cares about union-wide debt stabilization, then the more the fiscal reaction parameter, the higher the degree of a debt-concerned central banker. Correspondingly, since the inverse of the fiscal reaction parameter shows the reaction of the national fiscal authorities to changes in the country-specific outstanding level of debt, a high fiscal reaction parameter means lower changes to the output gap, so a lower degree of a debt-concerned central banker.

In the special case that the common central bank shares identical preferences with the social planner on union-wide output-gap stabilization, that is, $\alpha_S = \alpha_M$, and the latter only cares about pure cyclical macroeconomic stabilization, meaning $\gamma_S = 0$, the monetary authority should not be explicitly concerned with union-wide debt stabilization. It is not the social planner's preference for output-gap stabilization that matters, but the degree of conservatism of the monetary authority, with higher degree of conservatism leading to a more debt-concerned central banker. Moreover, in the special case that $\alpha_S = \alpha_M$ but $\gamma_S \neq 0$ it is optimal for the social planner not to impose on the monetary authority their preference for union-wide debt stabilization, but $\gamma_M = \frac{\delta_r\alpha_F\delta_g}{b_0}\gamma_S$. This makes sense, since in the decentralized regime the outstanding level of debt cannot be fully stabilized under supply shocks. Whether this preference should be stronger or not depends on specific structural and preference parameters. However, if the national fiscal authorities do not have short-run stabilization objectives, that is, $\alpha_F = 0$,

so they only care about country-specific debt stabilization, then it is optimal for the social planner not to appoint a debt-concerned central banker.

Equation (33) also shows that the optimal weight, γ_M, increases with the interest sensitivity of demand, δ_r, while it decreases with the already accumulated level of debt, b_0, since this is the impact of monetary policy on the outstanding level of debt. Thus, the monetary policy's relative effectiveness in stabilizing the output gap (relative to the outstanding level of debt) matters; in particular, it increases the optimal degree of a debt-concerned central banker.

5 | THE MARKET-BASED PREVENTIVE SOLUTION

A risk premium on country-specific nominal interest rates is assumed, according to the country-specific fiscal stances. This premium makes the two member-states face a nominal interest rate different from the one that is set by the monetary authority in the union. Moreover, under some circumstances, it can make the two interest rates differ. We are mainly interested in exploring the outcome for the policy mix and for debt stabilization, since the risk premium works as a preventive procedure on the part of the private sector, meaning the financial markets. The idea is to compare the two preventive procedures: (a) the authority-based one, which works through a debt-concerned monetary authority, and (b) the market-based one, through financial markets. In both cases, the national fiscal authorities remain debt-concerned.

We need to modify our model to incorporate country-specific nominal interest rates, instead of the common nominal interest rate. Thus, we define the following equations:

$$y_j = -\delta_r\left(i_j - \pi_j^e - \bar{r}_j\right) + \delta_g g_j + u_j, \tag{34}$$

$$b_j = \left(1 + i_j - \pi_j^e\right) b_0 + g_j, \tag{35}$$

$$i_j = i_M + \lambda g_j. \tag{36}$$

The first two equations are the corresponding aggregate demand and the debt accumulation equations (government budget constraint), namely Equations (1) and (7), respectively, when the country-specific nominal interest rate differs to the one set by the monetary authority, which is now denoted by i_M. Following Equation (36), this difference depends positively on the country-specific fiscal stance, since $\lambda > 0$; the parameter λ defines the risk premium parameter. Beetsma and Giuliodori (2010) report empirical evidence by Ardagna, Caselli, and Lane (2007) that an increase in the primary deficit raises the interest rate. We assume, for simplicity, that λ is the same for both member-states.[12] Equation (44) can be also found in Blueschke and Neck (2011) in a dynamic-game setting. There are studies assuming that the risk premium is affected by debt.[13] Beetsma and Giuliodori (2010) stress that in a more integrated financial market, an increase in the public debt leads to a smaller increase in the interest rate than under financial autonomy, hence financial markets will do a poorer job in deterring fiscal profligacy. We believe that this is more appropriate for dynamic games that have a long-run perspective. We analyse the standard decentralized case, following Section 3.1, and we investigate the difference because of the risk premium. Then, we compare this case with the one in the previous section, where we consider a debt-concerned monetary authority. We thus compare the two preventive procedures, the authority-based one with the market-based one. Finally, in Section 6, we consider the case of both a risk premium and a debt-concerned central banker, and we compute the optimal weight on union-wide debt stabilization.

The monetary authority's problem remains, delivering a monetary rule and equilibrium solutions for the output gap and the inflation rate at the union level described by Equations (10), (11), and (12), respectively. However, the country-specific fiscal rule changes. It now becomes:

$$b_j = -\frac{\alpha_F\left(\delta_g - \lambda\delta_r\right)}{1 + \lambda b_0} y_j, \tag{37}$$

where $\frac{dy_j}{dg_j} = \frac{\partial y_j}{\partial i_j} \times \frac{\partial i_j}{\partial g_j} + \frac{\partial y_j}{\partial g_j} = \delta_g - \lambda\delta_r$ and $\frac{db_j}{dg_j} = \frac{\partial b_j}{\partial i_j} \times \frac{\partial i_j}{\partial g_j} + \frac{\partial b_j}{\partial g_j} = 1 + \lambda b_0$. Equation (37) defines a trade-off between the country-specific outstanding level of debt and the output gap that is milder because of the risk premium; that is, the risk premium parameter reduces the fiscal reaction parameter (in absolute terms). The impact of fiscal policy on aggregate demand is now reduced, since it also increases the country-specific interest rate, while the latter increases the outstanding level of debt, too. It is plausible to assume that, in normal times, $\delta_g - \lambda\delta_r > 0$. In the opposite case that the risk premium parameter would be too high and/or the fiscal multiplier too low, the national fiscal authorities would choose not to trade-off the output gap with the outstanding level of debt, since the indirect effect of fiscal policy on aggregate demand through the country-specific interest rate is higher than the direct one. In this case, a contractionary fiscal policy has expansionary effects on aggregate demand. Moreover, the already accumulated level of debt does matter for the fiscal reaction, reducing the trade-off for the national fiscal

authorities, since it defines the impact of monetary policy on the country-specific outstanding level of debt.

At the union level, the outstanding level of debt can be found by averaging Equation (35), described again by Equation (8), while the union-wide fiscal rule is defined by averaging the country-specific one, namely Equation (37). The nominal interest rate in the union-wide government budget constraint is not the common nominal interest rate, but the union-wide one, defined by averaging the country-specific nominal interest rate (Equation (36)), as:

$$i = i_M + \lambda g. \tag{38}$$

Combining an average of Equation (37) with the equilibrium solution for the union-wide output gap, namely, Equation (12), we end up with the union-wide outstanding level of debt, as:

$$b = -\frac{\alpha_F\left(\delta_g - \lambda\delta_r\right)}{1+\lambda b_0} \times \frac{\omega}{\omega^2+\alpha_M}\epsilon. \tag{39}$$

This defines a milder change to union-wide supply shocks; hence more stabilization.

The two policy instruments at equilibrium are found to be:

$$\begin{aligned} i_M = \frac{1}{\delta_r + \delta_g b_0} \times \Bigg\{ & -\left(\delta_g - \lambda\delta_r\right) b_0 + (1+\lambda b_0) u \\ & - \left[1 + \lambda b_0 + \frac{\alpha_F\left(\delta_g - \lambda\delta_r\right)^2}{1+\lambda b_0}\right] \times \frac{\omega}{\omega^2+\alpha_M}\epsilon \Bigg\}, \end{aligned} \tag{40}$$

$$g = -\frac{1}{\delta_r + \delta_g b_0} \times \left\{ \delta_r b_0 + b_0 u + \left[\frac{\alpha_F \delta_r \left(\delta_g - \lambda\delta_r\right)}{1+\lambda b_0} - b_0\right] \times \frac{\omega}{\omega^2+\alpha_M}\epsilon \right\}. \tag{41}$$

Following Equation (40), the monetary authority reacts milder to the already accumulated level of debt, but stronger to union-wide demand shocks, since the impact of fiscal policy on aggregate demand is now lower. Regarding the union-wide fiscal stance, following Equation (41), the risk premium parameter affects the fiscal reaction only to union-wide supply shocks, which is now unambiguously milder, enhancing procyclicality, especially for a high enough already accumulated level of debt. Equation (41) no longer defines the common nominal interest rate, since with the existence of a risk premium there might not be one. Substituting Equations (40) and (41) to Equation (38), we compute the union-wide nominal interest rate at equilibrium, as:

$$i = \frac{1}{\delta_r + \delta_g b_0} \times \left\{ -\delta_g b_0 + u - \left[1 + \frac{\alpha_F \delta_g \left(\delta_g - \lambda\delta_r\right)}{1+\lambda b_0}\right] \times \frac{\omega}{\omega^2+\alpha_M}\epsilon \right\}. \tag{42}$$

Equation (42) shows that the reaction to union-wide supply shocks is milder.

The equilibrium solutions for the relative variables follow the benchmark decentralized case. In particular:

$$\begin{aligned} y_j - y_k &= \frac{(1+\lambda b_0)^2}{\alpha_F\left(\delta_g - \lambda\delta_r\right)^2 + (1+\lambda b_0)^2} \\ \left(u_j - u_k\right) &= -\frac{1+\lambda b_0}{\alpha_F\left(\delta_g - \lambda\delta_r\right)}\left(b_j - b_k\right), \end{aligned} \tag{43}$$

where $\frac{1+\lambda b_0}{\alpha_F\left(\delta_g - \lambda\delta_r\right)}$ is the inverse of the fiscal reaction parameter. The nominal interest rate differential can be found to be:

$$i_j - i_k = \lambda\left(g_j - g_k\right) = -\frac{\alpha_F\left(\delta_g - \lambda\delta_r\right)}{\alpha_F\left(\delta_g - \lambda\delta_r\right)^2 + (1+\lambda b_0)^2} \times \lambda\left(u_j - u_k\right). \tag{44}$$

The risk premium parameter affects both the country-specific output gap and the fiscal stance under asymmetric demand shocks. Thus, the country-specific nominal interest rates differ if there is a risk premium only under asymmetric demand shocks, as this creates an asymmetry in the fiscal stances.

We conclude this section by comparing the two preventive solutions, namely the authority-based one (following Section 4) with the market-based one, in terms of macroeconomic stabilization both at the union and national levels. The authority-based preventive solution delivers a less volatile union-wide (and country-specific) output gap, but a more volatile union-wide inflation rate. Regarding union-wide debt stabilization, the authority-based preventive solution is more efficient as long as the monetary authority's preference on union-wide debt stabilization exceeds a critical value, namely $\gamma_M > \frac{\left(\delta_r + \delta_g b_0\right)\left(\omega^2+\alpha_M\right)}{\alpha_F \delta_g b_0 \left(\delta_g - \lambda\delta_r\right)} \times \lambda\delta_r$. This critical value increases with the risk premium parameter, λ, the monetary authority's preference on output-gap stabilization, α_M, the interest sensitivity of aggregate demand, δ_r, and the slope of the PC equation, ω, while it deceases with the national fiscal authorities' preference on output-gap stabilization, α_F. The country-specific outstanding level of debt is less volatile in the authority-based preventive solution for supply shocks. For demand shocks, in order

for the risk premium case to deliver a less volatile country-specific outstanding level of debt, the risk premium parameter must exceed a critical value, namely $\lambda > \frac{\alpha_F \delta_g^2 - 1}{b_0 + \alpha_F \delta_g \delta_r}$, which decreases with the already accumulated level of debt, b_0.[14]

6 | DOES IT PAY TO BE DEBT-CONCERNED?

We investigate the case of a risk premium when the common central bank is also debt-concerned, following Section 4. Thus, we combine Sections 4 and 5. The monetary authority chooses its policy instrument, i_M, to minimize its loss function, given by Equation (29), subject to the union-wide descriptive Equations (3) and (4), the union-wide government budget constraint (debt accumulation equation) (Equation (8)) and the union-wide nominal interest rate, defined by Equation (38). The monetary rule follows Section 4, while the country-specific (so also the union-wide) fiscal rule follows Section 5; that is, Equations (31) and (37), respectively. Solving the system of equations by the usual way, we get the following equilibrium solutions at the union level:

$$\pi = -\frac{\alpha_M \delta_r (1+\lambda b_0) + \gamma_M \alpha_F b_0 \left(\delta_g - \lambda \delta_r\right)}{\delta_r (\omega^2 + \alpha_M)(1+\lambda b_0) + \gamma_M \alpha_F b_0 \left(\delta_g - \lambda \delta_r\right)} \epsilon, \quad (45)$$

$$y = \frac{\omega \delta_r (1+\lambda b_0)}{\delta_r (\omega^2 + \alpha_M)(1+\lambda b_0) + \gamma_M \alpha_F b_0 \left(\delta_g - \lambda \delta_r\right)} \epsilon, \quad (46)$$

$$b = -\frac{\omega \delta_r \alpha_F \left(\delta_g - \lambda \delta_r\right)}{\delta_r (\omega^2 + \alpha_M)(1+\lambda b_0) + \gamma_M \alpha_F b_0 \left(\delta_g - \lambda \delta_r\right)} \epsilon. \quad (47)$$

Following Equations (45) and (46), the debt-concerned monetary authority allows the risk premium parameter, λ, to affect the equilibrium union-wide inflation and the output gap. The equilibrium solutions for the two policy instruments can be found in section 'Appendix to Section 6'. The equilibrium solutions for the country-specific (relative) variables are exactly the same with the previous sections, given by Equations (43) and (44). Differences with Section 5 only exist for union-wide supply shocks, where all the macroeconomic variables are now more stabilized.

The aim of this section is the computation of the optimal weight on union-wide debt stabilization for the monetary authority, similarly to Section 4. We would like to investigate the impact of the risk premium parameter, λ, on the optimal weight on union-wide debt stabilization that the social planner imposes on the monetary authority in the monetary union. Thus, at stage 0, before the realization of shocks, the social planner chooses the optimal weight that the monetary authority places on union-wide debt stabilization, γ_M, by minimizing the expected value of Equation (32), subject to the union-wide equilibrium solutions (45)–(47). The optimal weight can be found to be:

$$\gamma_M = \frac{\delta_r}{b_0} \times \left[\frac{1+\lambda b_0}{\alpha_F \left(\delta_g - \lambda \delta_r\right)} (\alpha_S - \alpha_M) + \frac{\alpha_F \left(\delta_g - \lambda \delta_r\right)}{1+\lambda b_0} \gamma_S \right]. \quad (48)$$

Recall from Section 4 that it is optimal for the social planner to appoint a debt-concerned central banker as long as: (a) the social planner differs from the monetary authority in their weights towards union-wide output-gap stabilization, and (b) the social planner also cares about union-wide debt stabilization. Recall from Section 5 that $\frac{\alpha_F \left(\delta_g - \lambda \delta_r\right)}{1+\lambda b_0}$ defines the fiscal reaction parameter for the case of a risk premium, which is a decreasing function of the risk premium parameter. Following Equation (48), a higher risk premium parameter enhances the impact of the degree of conservatism on the optimal weight on union-wide debt stabilization, while it reduces the impact of the social planner's weight on union-wide debt stabilization.

In order to define the overall impact of the risk premium parameter on the optimal weight, γ_M, we get:

$$\frac{\partial \gamma_M}{\partial \lambda} = \frac{\delta_r + \delta_g b_0}{(1+\lambda b_0)^2 \left(\delta_g - \lambda \delta_r\right)^2} \times \left[\frac{\alpha_S - \alpha_M}{\alpha_F} (1+\lambda b_0)^2 - \alpha_F \gamma_S \left(\delta_g - \lambda \delta_r\right)^2 \right]. \quad (49)$$

It is straightforward that $\frac{\partial \gamma_M}{\partial \lambda} = 0$ for $\lambda = \lambda^c = \frac{\kappa \alpha_F \delta_g - 1}{b_0 + \kappa \alpha_F \delta_r}$, where $\kappa = \sqrt{\frac{\gamma_S}{\alpha_S - \alpha_M}}$. As long as this defines a minimum, then for $\lambda > \lambda^c$ the increase in the risk premium parameter increases the optimal degree of a debt-concerned central banker. This critical value is positively affected by the fiscal multiplier, and negatively affected by the degree of conservatism of the monetary authority and by the already accumulated level of debt.

7 | CONCLUSION

This article aims to answer a simple question: is it optimal for the social planner in a monetary union to appoint a debt-concerned monetary authority when (a) the national fiscal authorities are both debt-constrained and debt-concerned and (b) financial markets are preemptive? In order to do that, we assume a two-country monetary union where their fiscal authorities strategically interact between them and with a common central bank

when they face various shocks. The analysis provides a straightforward answer: it is desirable as long as: (a) there is a degree of conservatism in the monetary authority, and/or (b) the social planner cares about union-wide debt stabilization. The fiscal reaction parameter decreases the former's impact on the optimal weight on union-wide debt stabilization, while it increases the latter's. Since the risk premium parameter decreases the fiscal reaction parameter, it enhances the first impact and reduces the second one. Regarding the overall impact of the risk premium parameter on the optimal weight, there is a case for this to be positive, as long as the risk premium parameter exceeds a critical value. This critical value is positively affected by the fiscal multiplier, and negatively affected by the degree of conservatism in the monetary authority and by the already accumulated level of debt (or the impact of the country-specific interest rate on the outstanding level of debt).

A benchmark decentralized case in which all the authorities move simultaneously is compared to the fiscal-monetary (overall) policy coordination regime. The results can be summarized as follows: (a) for demand shocks, the two regimes deliver identical results; (b) for supply shocks, both the union-wide and country-specific outstanding level of debt are fully stabilized in the overall policy coordination regime, whereas both the union-wide and country-specific output gap are less volatile, compared with the benchmark decentralized case. However, this happens at the expense of inflation stabilization; (c) for supply shocks, the two national fiscal authorities prefer the overall policy coordination regime, whereas the monetary authority prefers the benchmark decentralized case.

We further consider two alternative cases in the decentralized strategic regime, in order to approximate the overall policy coordination regime. The first one assumes a debt-concerned monetary authority and considers the impact of the central bank's weight on union-wide debt stabilization on the policy mix. This is the authority-based preventive solution. The second one assumes that country-specific interest rates differ from the one being set by the central bank by a risk premium that positively depends on the country-specific fiscal stance; this is the market-based preventive solution. We find that the former case delivers a milder monetary reaction parameter, while the latter a milder fiscal reaction parameter. Thus, both cases stand between the benchmark decentralized case and the overall policy coordination strategic regime. By comparing the two preventive solutions, we find that the authority-based one delivers a less volatile union-wide output gap but a more volatile union-wide inflation rate. Regarding the union-wide debt stabilization, the authority-based preventive solution is more effective as long as the monetary authority's preference on union-wide debt stabilization exceeds a critical value, which increases with the risk premium parameter, the monetary authority's preference on output-gap stabilization relative to the fiscal authorities', the interest sensitivity of aggregate demand, and the slope of the PC equation. The country-specific outstanding level of debt is less volatile in the authority-based preventive solution for supply shocks. For demand shocks, in order for the risk premium case to deliver a less volatile country-specific outstanding level of debt, the risk premium parameter must exceed a critical value that decreases with the already accumulated level of debt.

One can think a lot of extensions to this setting: (a) assume that the risk premium is also affected by the other country's fiscal stance; this would also create a horizontal coordination problem, hence between the two national fiscal authorities; (b) deal with alternative strategic regimes regarding the sequence of moves; they would probably matter if the monetary authority is also debt-concerned (in this case, probably country-size asymmetry would matter, too); (c) assume Blanchard-Yaari consumers in that the AD equation will be also affected by the outstanding level of debt, following, for example, Kirsanova et al. (2005). We leave this work for future research.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study.

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ENDNOTES

[1] In a recent paper, Libich (2020) argues that the separation set-up of monetary and macro-prudential policies to different authorities is not desirable due to an inherent strategic conflict between those policies.

[2] Further references include Anevlavis et al. (2019), Engwerda, van Aarle, and Anevlavis (2019), Engwerda, van Aarle, Plasmans, and Weeren (2013), Tabellini (1986), and Vieira, Machado, and Ribeiro (2018).

[3] Also quoted in Hughes Hallett et al. (2011), Blanchard (2009) calls for the"...relegalization of shortcuts and of simple models".

[4] Alternatively, we could also assume that the fiscal authorities use government expenditure and adjust lump-sum taxes to achieve a certain amount of revenues. We thank an anonymous referee for pointing this to us.

[5] Moreover, in most of the literature potential output is assumed to be constant. Andersen (2008) and Chortareas and Mavrodimitrakis (2016) allow the fiscal stance to have short-run supply-side effects, too, by directly affecting the inflation rate. There is another strand in the literature that focuses on structural reforms

that change potential output, and their possible interactions with stabilization policies (see, for example, Beetsma & Giuliodori, 2010).

[6] Andersen (2008), for example, argues that strict inflation targeting may be considered as too rigid an interpretation of the monetary policy being pursued in the EMU. Assuming strict inflation targeting, that is, $\alpha_M = 0$, does not qualitatively change our results, but the assumption of flexible inflation targeting reveals that it is the degree of central bank's conservatism that matters for the optimal weight on debt stabilization, and not the social planner's preference on union-wide output-gap stabilization, per se. See Equation (33).

[7] An early reference is van Aarle, Bovenberg, and Raith (1995).

[8] For a formal derivation of Equation (7), see also Godbillon and Sidiropoulos (2001).

[9] It is important to note that in what follows, by simply setting $b_0 = 0$, we get the standard case in the literature where the national fiscal authorities are concerned with fiscal stance stabilization, as $b_j = g_j$.

[10] Details can be found in section 'Appendix to Section 3.3'.

[11] See section 'Appendix to Section 4'.

[12] An analysis for a different risk premium would probably demand for the already accumulated level of debt of the member-states to differ, too.

[13] Van Aarle (2013) assumes that the risk premium depends on debt instead of deficit in a closed-economy setting, while the author also allows for a stochastic shock. Neck and Blueschke (2014, 2016) allow for both deficit and debt in a monetary union, while in the former paper the authors also allow for a stochastic shock that means to capture a 'haircut penalty' by financial markets. In a recent paper, Anevlavis et al. (2019) assume that the risk premium is affected not only by debt, but also by the dynamics of debt, again in a dynamic-game setting for a closed economy, making the game a non-linear quadratic differential one; the dynamics of debt are provided by the debt accumulation equation. In Della Posta (2018), the risk premium is affected by the supply of bonds, by a public debt demand stochastic shock, and by the first derivative of the expected interest rate to time. The latter effect aims to capture the documented interest rate non-linearity in the euro area. The lower the expected sustainability of public debt, the higher the expected future variation of the interest rate, which in turns directly affects the current interest rate.

[14] Details can be found in section 'Appendix to Section 5'.

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How to cite this article: Mavrodimitrakis C. Debt stabilization and financial stability in a monetary union: Market versus authority-based preventive solutions. *Int J Fin Econ*. 2020;1–18. https://doi.org/10.1002/ijfe.2288

APPENDIX A.

Appendix to Section 3.3

We compare the two strategic regimes in terms of macroeconomic stabilization and welfare. For the output gap, we get:

$$Var(y)_{\epsilon}^{nc} - Var(y)_{\epsilon}^{c} = Var\left(y_j\right)_{\epsilon}^{nc} - Var\left(y_j\right)_{\epsilon}^{c} = \omega^2 Var(\epsilon) \times \left[\frac{1}{\left(\omega^2 + \alpha_M\right)^2} - \frac{1}{\left(\omega^2 + \alpha\right)^2}\right] > 0,$$

where '*nc*' and '*c*' stand for '*no coordination*' and '*coordination*', respectively. For the union-wide inflation rate, we get:

$$Var(\pi)_{\epsilon}^{nc} - Var(\pi)_{\epsilon}^{c} = -\frac{\omega^2 Var(\epsilon)}{\left(\omega^2 + \alpha_M\right)^2 \left(\omega^2 + \alpha\right)^2} \times \left[\left(\omega^2 + \alpha_M\right)\left(\alpha + \alpha_F\right) + \alpha_M \alpha_F\right] < 0.$$

Turning now to the welfare implications of the alternative policy regimes, under supply shocks, for the national fiscal authorities, we incorporate the solutions

for the country-specific output gap and outstanding level of debt for the two strategic regimes (Equations (18) and (19)) to the loss function (Equation (6)). We get:

$$E\left(L_{F_j}\right)_{\epsilon}^{nc}-E\left(L_{F_j}\right)_{\epsilon}^{c}=\frac{1}{2}\times\frac{\alpha_F^2+\omega^2 Var(\epsilon)}{\left(\omega^2+\alpha_M\right)^2\left(\omega^2+\alpha\right)^2}\times\left[\alpha_F+2\left(\omega^2+\alpha_M\right)+\delta_g^2\left(\omega^2+\alpha\right)^2\right]>0,$$

$$E\left(L_{F_j}\right)_{u}^{nc}=E\left(L_{F_j}\right)_{u}^{c}=\frac{1}{2}\times\frac{\alpha_F}{1+\alpha_F\delta_g^2}Var\left(u_j-u_k\right).$$

For the monetary authority, we incorporate the solutions for the union-wide output gap and the inflation rate for the two strategic regimes (Equations (11), (12), (24), and (25)) to the monetary authority's loss function, given by Equation (5). We get:

$$E(L_M)_{\epsilon}^{nc}-E(L_M)_{\epsilon}^{c}=-\frac{1}{2}\times\frac{\left(\alpha_F\omega\right)^2}{\left(\omega^2+\alpha_M\right)\left(\omega^2+\alpha\right)^2}Var(\epsilon)<0,$$

$$E(L_M)_{u}^{nc}=E(L_M)_{u}^{c}=0.$$

Appendix to Section 4

We report the union-wide equilibrium solutions by solving the model following the usual way:

$$y=\frac{\omega\delta_r}{\delta_r\left(\omega^2+\alpha_M\right)+\alpha_F\delta_g b_0\gamma_M}\epsilon,$$

$$\pi=-\frac{\alpha_M\delta_r+\alpha_F\delta_g b_0\gamma_M}{\delta_r\left(\omega^2+\alpha_M\right)+\alpha_F\delta_g b_0\gamma_M}\epsilon,$$

$$b=-\frac{\alpha_F\delta_g\delta_r\omega}{\delta_r\left(\omega^2+\alpha_M\right)+\alpha_F\delta_g b_0\gamma_M}\epsilon.$$

Equilibrium solutions for the policy instruments are given by:

$$i=\frac{1}{\delta_r+\delta_g b_0}\times\left[-\delta_g b_0+u-\frac{\omega\delta_r\left(1+\alpha_F\delta_g^2\right)}{\delta_r\left(\omega^2+\alpha_M\right)+\alpha_F\delta_g b_0\gamma_M}\epsilon\right],$$

$$g=\frac{\delta_r}{\delta_r+\delta_g b_0}\times\left[-b_0-b_0u+\frac{\omega\left(b_0-\alpha_F\delta_g\delta_r\right)}{\delta_r\left(\omega^2+\alpha_M\right)+\alpha_F\delta_g b_0\gamma_M}\epsilon\right].$$

The relative equilibrium solutions are exactly the same as before.

We proceed to macroeconomic stabilization comparisons between the debt stabilization regime and the standard non-cooperative (decentralized) regime of Section 3.1; the '*ds*' abbreviation stands for '*debt stabilization*'. We define $\mu=\frac{1}{\delta_r\left(\omega^2+\alpha_M\right)+\gamma_M\alpha_F\delta_g b_0}$. We get:

$$Var(\pi)_{\epsilon}^{ds}-Var(\pi)_{\epsilon}^{nc}=\frac{\gamma_M\alpha_F\delta_g b_0\mu\omega^2}{\left(\omega^2+\alpha_M\right)^2}\times Var(\epsilon)\times\left(2\alpha_M+\gamma_M\alpha_F\delta_g b_0\mu\omega^2\right)>0,$$

$$Var(y)_{\epsilon}^{ds}-Var(y)_{\epsilon}^{nc}=-\frac{\gamma_M\alpha_F\delta_g b_0\mu\omega^2}{\left(\omega^2+\alpha_M\right)^2}\times Var(\epsilon)\times\left[1+\delta_r\mu\left(\omega^2+\alpha_M\right)\right]<0,$$

$$Var(b)_{\epsilon}^{ds}-Var(b)_{\epsilon}^{nc}=\left(\alpha_F\delta_g\right)^2\left[Var(y)_{\epsilon}^{ds}-Var(y)_{\epsilon}^{nc}\right]<0,$$

$$Var\left(y_j\right)_{\epsilon}^{ds}-Var\left(y_j\right)_{\epsilon}^{nc}=-\frac{\gamma_M\alpha_F\delta_g b_0\mu\omega^2}{\omega^2+\alpha_M)^2}\times Var(\epsilon)\times\left[1+{}_r\mu\left(\omega^2+\alpha_M\right)\right]<0,$$

$$Var\left(b_j\right)_{\epsilon}^{ds}-Var\left(b_j\right)_{\epsilon}^{nc}=\left(\alpha_F\delta_g\right)^2\left[Var\left(y_j\right)_{\epsilon}^{ds}-Var\left(y_j\right)_{\epsilon}^{nc}\right]<0,$$

$$Var\left(g_j\right)_{\epsilon}^{ds}-Var\left(g_j\right)_{\epsilon}^{nc}=-\frac{\gamma_M\alpha_F\delta_g b_0\mu\left(b_0-\alpha_F\delta_g\delta_r\right)^2\omega^2}{\left[\left(\delta_r+\delta_g b_0\right)^2\left(\omega^2+\alpha_M\right)\right]^2}\times Var(\epsilon)\times\left[1+\delta_r\mu\left(\omega^2+\alpha_M\right)\right]<0.$$

Last but not least, we compare the expected losses of the two national fiscal authorities for the two cases, as:

$$E\left(L_{F_j}\right)_{\epsilon}^{ds}-E\left(L_{F_j}\right)_{\epsilon}^{nc}=\frac{1}{2}\times\alpha_F\left(1+\alpha_F\delta_g^2\right)\times\left[Var\left(y_j\right)_{\epsilon}^{ds}-Var\left(y_j\right)_{\epsilon}^{nc}\right]<0.$$

Appendix to Section 5

We compare and contrast the two preventive procedures in terms of macroeconomic stabilization. At the union level, we get:

$$Var(\pi)^{ds}-Var(\pi)^{rp}=\frac{\gamma_M\alpha_F\delta_g b_0\omega^2}{\left(\omega^2+\alpha_M\right)A}\times\left(\frac{\alpha_M\delta_r+\gamma_M\alpha_F\delta_g b_0}{A}+\frac{\alpha_M}{\omega^2+\alpha_M}\right)Var(\epsilon)>0,$$

$$Var(y)^{ds}-Var(y)^{rp}=-\frac{\gamma_M\alpha_F\delta_g b_0\omega^2}{\left(\omega^2+\alpha_M\right)A}\times\left(\frac{\delta_r}{A}+\frac{1}{\omega^2+\alpha_M}\right)Var(\epsilon)<0,$$

$$Var(b)^{ds}-Var(b)^{rp}=\frac{\left(\alpha_F\omega\right)^2}{\left(1+\lambda b_0\right)\left(\omega^2+\alpha_M\right)A}\times\left[\frac{\delta_g\delta_r}{A}+\frac{\delta_g-\lambda\delta_r}{\left(1+\lambda b_0\right)\left(\omega^2+\alpha_M\right)}\right]\times BVar(\epsilon),$$

where '*rp*' stands for '*risk premium*' and $A=\delta_r\left(\omega^2+\alpha_M\right)+\gamma_M\alpha_F\delta_g b_0$ and $B=\lambda\delta_r\left(\delta_r+\delta_g b_0\right)\left(\omega^2+\alpha_M\right)-\left(\delta_g-\lambda\delta_r\right)\gamma_M\alpha_F\delta_g b_0$. Turning now to country-specific variables, we distinguish between demand and supply shocks. For supply shocks, we find that:

$$Var\left(y_j\right)_{\epsilon}^{ds}-Var\left(y_j\right)_{\epsilon}^{rp}=Var(y)^{ds}-Var(y)^{rp}<0,$$

$$Var\left(b_j\right)_{\epsilon}^{ds}-Var\left(b_j\right)_{\epsilon}^{rp}=Var(b)^{ds}-Var(b)^{rp}.$$

For demand shocks, we get:

$$Var\left(y_j\right)_u^{ds} - Var\left(y_j\right)_u^{rp} = -\frac{1}{4}Var\left(u_j - u_k\right) \times \left[\frac{1}{1+\alpha_F\delta_g^2} + \frac{1+\lambda b_0}{\alpha_F\left(\delta_g - \lambda\delta_r\right)^2 + \left(1+\lambda b_0\right)^2}\right] \times \frac{\lambda\alpha_F\left[\delta_g - \lambda\delta_r + \delta_g\left(1+\lambda b_0\right)\right]\left(\delta_r + \delta_g b_0\right)}{\left[\alpha_F\left(\delta_g - \lambda\delta_r\right)^2 + \left(1+\lambda b_0\right)^2\right]\left(1+\alpha_F\delta_g^2\right)},$$

which is more possible to be negative, and it is definitely so for $\delta_g - \lambda\delta_r > 0$, and:

$$Var\left(b_j\right)_u^{ds} - Var\left(b_j\right)_u^{rp} = \frac{1}{4}Var\left(u_j - u_k\right) \times \left[\frac{\delta_g}{1+\alpha_F\delta_g^2} + \frac{\left(\delta_g - \lambda\delta_r\right)\left(1+\lambda b_0\right)}{C}\right] \times \frac{\lambda\alpha_F^2\left(\delta_r + \delta_g b_0\right)}{C\left(1+\alpha_F\delta_g^2\right)} \times \left[1 + \lambda b_0 - \alpha_F\delta_g\left(\delta_g - \lambda\delta_r\right)\right],$$

where $C = \alpha_F(\delta_g - \lambda\delta_r)^2 + (1 + \lambda b_0)^2$.

Appendix Section 6

The model is solved by the usual way. The two policy instruments at the union level can be found to be:

$$g = -\frac{1}{\delta_r + \delta_g b_0} \times \left[\delta_r b_0 + b_0 u - \omega\delta_r \frac{\left(1+\lambda b_0\right)b_0 - \alpha_F\left(\delta_g - \lambda\delta_r\right)\delta_r}{\delta_r(\omega^2 + \alpha_M)\left(1+\lambda b_0\right) + \gamma_M\alpha_F b_0\left(\delta_g - \lambda\delta_r\right)}\epsilon\right],$$

$$i_M = \frac{1}{\delta_r + \delta_g b_0} \times \left[-\left(\delta_g - \lambda\delta_r\right)b_0 + \left(1+\lambda b_0\right)u - \omega\delta_r \frac{\left(1+\lambda b_0\right)^2 + \alpha_F\left(\delta_g - \lambda\delta_r\right)^2}{\delta_r(\omega^2 + \alpha_M)\left(1+\lambda b_0\right) + \gamma_M\alpha_F b_0\left(\delta_g - \lambda\delta_r\right)}\epsilon\right].$$