Debt and Taxes: Optimal Fiscal Consolidation in the Small Open Economy*

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Abstract

In this paper, I argue that the optimal design of a fiscal consolidation plan must consider the transition dynamics of the economy and be chosen such that either welfare (or another given measure of prosperity) is maximized. In the context of a small open economy, I study the optimal design of a fiscal consolidation plan under different monetary policy regimes and, in particular, the implications of reducing debt under a currency peg. Two main lessons are derived from the results. First, consolidation is costly enough regarding welfare, so that the fiscal authority would like to implement it at a very slow pace. If the government is forced to do it by a certain deadline, the welfare maximizing path will reduce the losses but will not be able to offset them. Second, from the output perspective, the optimal consolidation path under an independent monetary regime leads to a positive response of aggregate demand. While, under the currency peg, the optimal path induces an economic recession. Devaluation seems to be a key factor in stabilizing output during fiscal consolidation.

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1 Introduction

"In this world nothing can be said to be certain, except death and taxes"

Benjamin Franklin, 1789

The recent economic crisis ignited an unsettled global debate on fiscal consolidation and debt reduction. From 2008 to 2012, most developed countries faced a severe sovereign debt crisis that caused interest rate premiums on government debt to rise to unprecedented levels. The crisis was particularly hard in Greece, Ireland, Italy, Spain, and Portugal; but its consequences were felt all around the developed world.

Imposing a no-Ponzi condition, the current stock of outstanding government debt must equal the present discounted value of future fiscal surpluses. Hence, solving a debt crisis necessitates adjusting taxes, government spending, or both. From the policy perspective, a fiscal authority looking to engage in fiscal consolidation has many possible alternatives. For example, it could implement a plan mostly focused on spending reductions, or instead could feature tax increases. Moreover, there is an important intertemporal dimension to fiscal consolidation: governments could reduce debt by raising taxes and cutting government expenditure immediately (or in the near future), or by promising to do so at some far off date in the future.

There has been some empirical work analyzing the macroeconomic consequences of different fiscal consolidation plans. In the aftermath of the European crisis, evidence suggests that those countries who implemented the fastest consolidation plans recovered growth and employment faster compared to those countries whose consolidations were more drawn out (Blanchard et al., 2013; Perotti, 2012). In contrast to this empirical work, to the best of my knowledge, the optimal design of fiscal consolidation plans has not been studied in a quantitative general equilibrium modeling framework.

In this paper, I argue that the optimal design of a fiscal consolidation plan must consider the transition dynamics of the economy and be chosen such that either welfare (or another given measure of prosperity) is maximized. This paper aims to make a contribution to the literature by studying what is the optimal path for government spending and labor taxes that, in the context of a small open economy, achieves fiscal consolidation and maximize either welfare or the response of output. Furthermore, I study the optimal consolidation path under different monetary policy regimes and, in particular, the implications of conducting fiscal consolidation under a currency peg. From doing this, I can draw some lessons for the smallest members of the European Union.

To give an answer to these questions, I use a modified version of Gali and Monacelli (2008) small open economy new Keynesian model. The model includes non-ricardian households and a fiscal authority that is fully committed to debt consolidation when mandated to do so [1]. To find the optimal path towards consolidation, I assume that, once the mandate to reduce debt is given, the fiscal authority will choose the sequences of public spending and taxes such that the present discounted value of flow utility (or output) is maximized.

So far, theoretical or simulation-based studies have focused its efforts to answer whether fiscal consolidations should be expenditure or taxed-based?; and whether its effects over output are expansionary or contractionary. In these studies, the specific design details of the consolidation path are indirectly determined by the answer to the previous questions. If consolidations are expansionary, the reforms should be adopted it as soon as possible. If consolidations are contractionary, a more flexible and gradual path is likely the best for the economy. However, the problem with this approach is that the literature has given mostly ambivalent answers to the aforementioned questions.

For instance, Coenen et al. (2008) find that there is a clear trade-off between short and long run. In the long run, fiscal consolidation has positive effects on output and consumption (notably from lower distortionary taxes). In the short run, even if the implementation is gradual and fully anticipated, both expenditure and tax based reforms will have adjustment costs over output. In contrast, Cogan et al. (2013), find that a fiscal consolidation strategy involving any mix of tax and government spending reforms will have short and long-run positive effects over output. In its turn, Erceg and Lindé (2013) find that under a constrained monetary authority, tax-based fiscal consolidations have smaller adverse effects on output.

In contrast to the aforementioned studies, the results presented in this paper define the optimal fiscal consolidation plan in terms of the transition dynamics that maximizes either welfare or output. I find that spending-based consolidations are better for output than revenue-based consolidations. A result that is consistent with the empirical work Alesina and Ardagna (1998), Alesina and Ardagna (2013) and Perotti (1999). When the fiscal authority wants to maximize the response of output, I find that the optimal path commands a dramatic reduction in public spending. By doing this, consumption will react positively to a sharp reduction in taxes.

Furthermore, the implied real depreciation will boost exports and give extra help to domestic aggregate demand. In a country with an independent monetary authority, debt reduction could be achieved optimally without hurting growth. In contrast, with a currency peg, the inability of the central bank to depreciate the currency will dampen the response of output. Since the terms of trade do not react as much, the extra stimulus coming from external demand is more

[1] An important implicit assumption in my model is that consolidation is imposed exogenously. More precisely, the mandate to reduce debt implies that the economy will be targeting an exogenously determined steady state debt-to-GDP value. This can be interpreted as the Troika (European Union, European Central Bank, and International Monetary Fund) imposing a particular debt target.

muted.

Regarding welfare, results are mixed. Without a specific time limit, the fiscal authority finds optimal to do the adjustment at a very slow pace. The economy will eventually converge to the exogenously determined debt-to-GDP target, but the requiered reforms will be gradually implemented. By doing this, the fiscal authority is effectively neutralizing, in the present value sense, all the short term welfare loses associated with the adjustment. When imposing a deadline, the fiscal authority will reduce debt in the given time but will not be able to set a path the eliminates the welfare losses.

Two important lessons are derived from these results. First, from the output perspective, the ability to control the nominal interest rate and to depreciate the currency allows the fiscal authority to put into action a consolidation plan that completely offsets the short-term costs of reducing debt massively. In a country with no independent monetary authority, like the smallest members of the European Union, even the optimal consolidation plan will lead the country into a recession. Second, from the welfare perspective, no easy option is available. Reducing debt aggressively is costly for welfare even in the optimal case. In general, the slowest the implementation, the better for welfare. Furthermore, when the fiscal authority is constrained by a time limit, no significant differences were observed across different monetary policy regimes.

The paper is organized as follows. In Section II, I discuss the model and all the theoretical machinery used to answer my research question. Section III, presents different consolidation experiments and results. Last but not least, section IV concludes and discusses some caveats and ideas for future research.

2 The Model

In this section, I will describe a small open economy and its interactions with the rest of the world. The model presented here is based on Gali and Monacelli (2008) which is a modern and tractable DSGE model with nominal rigidities. The model describes an economy composed of forward-looking non-ricardian households, firms, and a government. The economy is assumed to be part of a continuum of economies represented by the unit interval and sufficiently small so that it will not affect the global economy.

Households can buy domestic and foreign goods, and to trade foreign assets in a complete financial market. The non-ricardian features of this model will be added thanks to a distortionary tax on labor income. From the production side, a continuum of firms represented by the unit interval will produce differentiated goods. Nominal rigidities will be motivated by the assumption of monopolistic competition among these firms and Calvo pricing.

On the fiscal side, the government will also consume intermediate goods that will be received by the households in the form of an aggregate public consumption index. Government spending is non-wasteful as it gives utility to the households. The government finances its operation using debt and tax revenues. Public debt is only available to domestic households and cannot be traded internationally. To guarantee the stability of debt, taxes and public spending will be subject to fiscal rules that adjust in response to deviations of debt from the its steady state value. On the aggregate side, the economy will be subject to shocks to productivity and the global economy.

Before proceeding with the description of the model, a note on notation is mandatory. From now on, variables denoted with a k index will represent variables corresponding to country k where $k \in [0, 1]$. For example, C_t^k will indicate country's k total consumption. Variables denoted by an $*$ will represent variables associated with the world, for example, Y_t^* refers to global output. Variables without a time subscript denote steady-states.

This section is organized as follows. First, I describe the household and the firm's optimization problem. Then, I introduce the fiscal and the monetary authority. Finally, I conclude my model description with the market clearing and aggregate conditions that characterize the equilibrium.

2.1 Households

The economy will be inhabited by a representative household who will be able to consume, supply labor, accumulate bonds and hold shares in the firms. The household's utility will be a function of total consumption, labor and the supply of public goods

$$U\left(C_t,\, N_t,\, G_t\right) = \ln C_t - \psi \frac{N_t^{1+\varphi}}{1+\varphi} + \chi \ln G_t \tag{1}$$

where φ denotes the inverse Frisch elasticity of Labor supply; ψ is on weight on labor (N_t) and χ a weight on public goods (G_t) supplied by the government. C_t denotes total consumption and will be a composite index of consumption of domestic goods ($C_{H,t}$) and consumption of foreign goods ($C_{F,t}$)

$$C_t = \frac{1}{(1-\alpha)^{(1-\alpha)}\,\alpha^{\alpha}} C_{F,t}^{\alpha} C_{H,t}^{1-\alpha} \tag{2}$$

where $\alpha \in [0, 1]$ can be interpreted as the degree of openness of the economy. Conversely, $1-\alpha$ will denote the degree of home bias (preference for domestic goods). The household will be able to choose consumption among a continuum of differentiated domestic and foreign goods denoted by j where $j \in [0, 1]$. Consumption of domestic goods $C_{H,t}$ will be defined as an index that aggregates over the consumption of domestic variety j

$$C_{H,t} = \left[\int_0^1 C_{H,t}\left(j\right)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}} \tag{3}$$

where $\epsilon > 1$ is the elasticity of substitution across different domestic varieties j. Consumption of foreign goods will be defined as an index of imported varieties across all countries

$$C_{F,\,t} = \exp \int_0^1 \ln C_{k,t} dk \tag{4}$$

where $C_{k,t}$ refers to total goods imported from country k and is given by

$$C_{k,\,t} = \left(\int_0^1 C_{k,\,t}\,(j)^{\frac{\epsilon-1}{\epsilon}}\, dj \right)^{\frac{\epsilon}{\epsilon-1}} \tag{5}$$

where $C_{k,\,t}\,(j)$ denotes consumption of the foreign variety j. As mentioned before, each household will decide over the amount of domestic and foreign goods that consumes; the amount of labor it supplies, and the amount of bonds it buys or sell. Assuming that the law of one price holds at all times, the household's optimal decision will be constrained by the nominal budget constraint

$$\int_0^1 P_{H,\,t}\,(j)\, C_{H,\,t}\,(j)\, dj + \int_0^1 \int_0^1 P_{k,\,t}\,(j)\, C_{k,\,t}\,(j)\, dj dk + E_t \left[\mathcal{Q}_{t,t+1} B_{t+1} \right] \leq$$
$$(1 - \tau_t)\, W_t N_t + \Pi_t + B_t \tag{6}$$

where the left-hand side of the inequality denotes expenditures, and the right-hand side refers to income. $P_{k,t}\,(j)$ denotes the price of good j produced at country k. B_t refers to gross bond holdings denominated in domestic currency. W_t, τ_t and N_t, denote nominal wage, labor tax rate and labor, respectively. $Q_{t,\,t+1}$ is the stochastic discount factor pricing the payoff of a one-period bond[2]. Π_t denotes the profits trasfered from the firms to the household.

Since preferences are based on a CES aggregator, we can solve by first choosing the mix of varieties that minimize costs, and then we choose the total amount to maximize utility[3]. Following this plan, we get that the optimal demand function for the domestic good j

$$C_{H,\,t}\,(j) = \left[\frac{P_{H,\,t}\,(j)}{P_{H,\,t}} \right]^{-\epsilon} C_{H,\,t} \quad \forall\; j \in [0,\,1] \tag{7}$$

where the index of prices for domestically produced goods $(P_{H,\,t})$ will be defined as

$$P_{H,\,t} = \left(\int_0^1 P_{H,\,t}\,(j)^{1-\epsilon}\, dj \right)^{\frac{1}{1-\epsilon}} \tag{8}$$

An analogous procedure for expenditures on variety j coming from any given country k yields

[2]Note that since I am assuming that preferences are identical across countries, $\mathcal{Q}_{t,\,t+1}$ will be common to both domestic and foreign households

[3]See Appendix A for more details.

the optimal demand function

$$C_{k,\,t}\,(j) = \left[\frac{P_{k,\,t}\,(j)}{P_{k,\,t}}\right]^{-\epsilon} C_{k,\,t} \;\; \forall\; j \in [0,\,1] \tag{9}$$

where $P_{k,\,t} = \left[\int_0^1 P_{k,\,t}\,(j)^{1-\epsilon}\, dj\right]^{\frac{1}{1-\epsilon}}$ is the price index for goods imported from country k. Similarly, the demand for foreign goods by country of origin is given by

$$C_{k,\,t} = \left(\frac{P_{F,\,t}}{P_{k,\,t}}\right) C_{F,t} \tag{10}$$

where the price index for imported goods ($P_{F,\,t}$), expressed in domestic currency is given by

$$P_{F,\,t} = \exp \int_0^1 \ln P_{k,\,t} dk \;\; \forall\; k \;\in\; [0,\,1] \tag{11}$$

Combining equations (7) and (9) with the price index definitions yields that

$$P_{H,\,t}C_{H,\,t} = \int_0^1 P_{H,\,t}\,(j)\, C_{H,\,t}\,(j)\, dj \tag{12}$$

$$P_{k,\,t}C_{k,\,t} = \int_0^1 P_{k,\,t}\,(j)\, C_{k,\,t}\,(j)\, dj \tag{13}$$

And in particular, using equation (11) and the optimal demand for imported goods by country of origin, total expenditures on imported goods can be written as

$$P_{F,\,t}C_{F,\,t} = \int_0^1 P_{k,\,t}C_{k,\,t} dk = \int_0^1 \int_0^1 P_{k,\,t}\,(j)\, C_{k,\,t}\,(j)\, dj dk \tag{14}$$

Now, given (12) and (14), the optimal demands for domestic and foreign goods can be found by solving the following expenditure minimization problem

$$\min_{C_{H,\,t},\; C_{F,\,t}} \quad P_{H,\,t}C_{H,\,t} + P_{F,\,t}C_{F,\,t}$$

$$s.t \;\; C_t = \frac{1}{(1-\alpha)^{(1-\alpha)}\, \alpha^{\alpha}} C_{F,\,t}^{\alpha} C_{H,\,t}^{1-\alpha}$$

Define the aggregate price index as $P_t = P_{F,\,t}^{\alpha} P_{H,\,t}^{1-\alpha}$, then the optimal allocation of any given expenditure on domestic and foreign goods is given by

$$C_{H,\,t} = (1-\alpha)\left(\frac{P_{H,\,t}}{P_t}\right)^{-1} C_t \tag{15}$$

$$C_{F,\,t} = \alpha \left(\frac{P_{F,\,t}}{P_t}\right)^{-1} C_t \tag{16}$$

Note that combining equations (13), (15) and (16) we get that total expenditures on consumption can be written as

$$P_t C_t = P_{H,t} C_{H,t} + P_{F,t} C_{F,t}$$

Substituting into the budget constraint described in equation (6), allow us to write the household optimization problem as

$$\max_{C_t, N_t, B_{t+1}} \quad E_0 \sum_{t=0}^{\infty} \beta^t \left(\ln C_t - \psi \frac{N_t^{1+\varphi}}{1+\varphi} + \chi \ln G_t \right) \tag{17}$$

subject to

$$P_t C_t + E_t \left[\mathcal{Q}_{t,t+1} B_{t+1} \right] \leq \ (1 - \tau_t) W_t N_t + \Pi_t + B_t \tag{18}$$

which yields the following simplified first order conditions

$$E_t \mathcal{Q}_{t,\,t+1} = \beta E_t \left[\frac{C_t}{C_{t+1}} \frac{1}{(1+\pi_{t+1})} \right] \tag{19}$$

$$N_t^{\varphi} = \frac{1}{\psi} \frac{(1-\tau_t) W_t}{P_t C_t} \tag{20}$$

where π_{t+1} is the aggregate inflation rate and is defined as $(1 + \pi_{t+1}) = \frac{P_{t+1}}{P_t}$. Now, let the real wage as $w_t = \frac{W_t}{P_t}$ and equation (20) becomes

$$N_t^{\varphi} = \frac{1}{\psi} \frac{(1-\tau_t) w_t}{C_t} \tag{21}$$

Equation (19) tell us that at the optimum, the representative household will be indifferent between consuming one more unit today and saving it for consumption tomorrow. Equation (21) defines the optimal condition for labor supply. The labor decision will be distorted by the presence of the tax rate. The household will offer units of labor up to the point where the marginal disutility of labor is equal to the marginal utility of consumption times the after-tax compensation for work.

Now, following Gali and Monacelli (2008), I will assume that financial markets are complete and frictionless. This means that both domestic and foreign households have access to the same kind of assets. In other words, an Euler equation identical to (19) must hold for the foreign household[4]

$$\beta E_t \left[\left(\frac{C^*_{t+1}}{C^*_t} \right)^{-\sigma} \frac{P^*_t}{P^*_{t+1}} \frac{\mathcal{E}_t}{\mathcal{E}_{t+1}} \right] = E_t [\mathcal{Q}_{t,\,t+1}] \tag{22}$$

where the bond's payoff is expressed in terms of the domestic currency. Now, define the effective

[4]Recall that variables marked with * refer to world variables.

real exchange rate[5] as $\mathcal{Z}_t = \frac{\mathcal{E}_t P_t^*}{P_t}$, substitute into (22) and iterate forward to get

$$C_t = \mathcal{Z}_t C_t^* \nu$$

Where ν is a constant that will depend on initial conditions on net asset holdings (Gali and Monacelli, 2008). In particular, assuming zero net foreign asset holdings, it is possible to show that $\nu = 1$. Therefore, we can relate domestic consumption to world consumption thru the real exchange rate

$$C_t = \mathcal{Z}_t C_t^*$$

Morever, defining the terms of trade (S_t) as the price of imports in terms of home goods, we get that

$$S_t = \frac{P_{F,t}}{P_{H,t}} \tag{23}$$

which allow us to write domestic consumption as a function of the terms of trade and global consumption

$$C_t = C_t^* S_t^{1-\alpha} \tag{24}$$

where the last equality derives from the fact that the price of foreign goods in terms of domestic currency is given by $P_{F,t} = \mathcal{E}_t P_t^*$ and the aggregate price index can be written as

$$P_t = P_{H,t} S_t^{\alpha} \tag{25}$$

On a final note, it is worth noting that the aggregate price index described by equation (25) can be written in terms of inflation and the terms of trade

$$\frac{P_t}{P_{t-1}} = \frac{P_{H,t}}{P_{H,t-1}} \left(\frac{P_{H,t-1}}{P_{t-1}} \right) S_t^{\alpha}$$
$$\frac{P_t}{P_{t-1}} = \frac{P_{H,t}}{P_{H,t-1}} \left(\frac{S_t}{S_{t-1}} \right)^{\alpha}$$

Define domestic inflation as $(1 + \pi_{H,t}) = \frac{P_{H,t}}{P_{H,t-1}}$ and substitute to get

$$(1 + \pi_t) = (1 + \pi_{H,t}) \left(\frac{S_t}{S_{t-1}} \right)^{\alpha} \tag{26}$$

2.2 Production

As mentioned before, a continuum of firms represented by the unit interval will produce differentiated goods denoted by j where $j \in [0, 1]$. These firms will operate under monopolistic

[5]Note that it is also possible to define the *bilateral* exchange rate as $\mathcal{Z}_{k,t} = \frac{\mathcal{E}_{k,t} P_t^k}{P_t}$. Moreover, the world prices are $P_t^* = \exp \int_0^1 \ln P_t^k dk$ and $\mathcal{Z}_t = \exp \int_0^1 \ln \mathcal{Z}_{k,t} dk$

competition and will behave as price setters. Nominal rigidities will be introduced under the assumption that firms face *a la* Calvo staggered pricing (Calvo, 1983). Producers will use constant returns to scale technology in labor

$$Y_t\,(j) = A_t N_t(j) \tag{27}$$

where A_t is an stochastic productivity shock. The Calvo (1983) assumption implies that each period there will be a fixed probability $(1-\phi)$ that the firm is not able to freely adjust prices to maximize profit. Notwithstanding, it will be able to optimally choose labor to minimize cost subject to production, being at least, equal to demand. In that sense, the minimization cost problem is given by

$$\begin{aligned} \min_{N_t(j)} \quad & W_t N_t\,(j) \\ s.t \quad & A_t N_t\,(j) \geq Y_t\,(j) \end{aligned}$$

Solving the first order condition, we get the optimal solution is

$$\varrho\,(j) = \frac{W_t}{A_t} \tag{28}$$

where $\varrho_t(j)$ is the lagrange multiplier and can be interpreted as the nominal marginal cost for the j^{th} producer. However, since each producer faces the same productivity shocks and the same wage, the marginal cost must also be common to each producer. Dropping the j index and dividing by the domestic price index, the real marginal cost is given by

$$mc_t = \frac{W_t}{A_t P_{H,t}}$$

Moreover, multiplying and dividing by P_t, we get the real marginal cost as a function of the terms of trade and real wage

$$mc_t = \frac{w_t}{A_t} S_t^{\alpha} \tag{29}$$

2.2.1 Price Setting

As mentioned before, each period there will be a fixed probability $1-\phi$ that a firm can adjust its domestic price. To set a new price, the firm must consider the possibility that she gets stuck with it for several periods. In particular, the firm must choose the price that maximizes the intertemporal flow of profits generated while the price remains effective. To do this, first, the firm knows that domestic demand for variety j will be given by

$$Y_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon} Y_t \tag{30}$$

where Y_t is the aggregate domestic demand and is given by

$$Y_t = \left(\int_0^1 Y_t(j)^{\frac{\epsilon-1}{\epsilon}} \right)^{\frac{\epsilon}{\epsilon-1}} \tag{31}$$

Then, the dynamic optimization problem of the firm is given by

$$\max_{P_{H,t}(j)} \quad E_t \sum_{s=0}^{\infty} (\beta\phi)^s \frac{u'(C_{t+s})}{u'(C_t)} \left(P_{H,t}(j)^{1-\epsilon} P_{H,t+s}^{\epsilon-1} Y_{t+s} - mc_{t+s} P_{H,t}(j)^{-\epsilon} P_{H,t+s}^{\epsilon} Y_{t+s} \right) \tag{32}$$

where firms discount the future using the household's stochastic discount factor. After simplifying the first order condition, we get the optimal domestic reset price

$$P_{H,t}^{\#}(j) = \frac{\epsilon}{\epsilon - 1} \left[\frac{X_{1,t}}{X_{2,t}} \right] \tag{33}$$

where

$$X_{1,t} = u'(C_t)\, mc_t P_{H,t}^{\epsilon} Y_t + \phi\beta E_t X_{1,t+1} \tag{34}$$

$$X_{2,t} = u'(C_t)\, P_{H,t}^{\epsilon-1} Y_t + \phi\beta E_t X_{2,t+1} \tag{35}$$

The optimal price is given by the desired markup $\mathcal{M} = \frac{\epsilon}{\epsilon-1}$ over the expected flow of marginal costs weighted by the probability that the price remains effective at any given horizon. Furthermore, note that nothing in equation (33) depends on j, which means that all firms choose the same reset price.

2.3 Fiscal Authority

The government will choose to consume intermediate domestic goods from a continuum of differentiated varieties denoted by j where $j \in [0, 1]$. Total public consumption will be given by the index

$$G_t = \left(\int_0^1 G_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right)^{\frac{\epsilon}{\epsilon-1}} \tag{36}$$

where $\epsilon > 1$ is the elasticity of substitution across different domestic varieties j and $G_t(j)$ denotes the level of consumption of good j. Since the goverment minimizes costs, the optimal demand for the variety j will be given by

$$G_t(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\epsilon} G_t \tag{37}$$

where $P_{H,t}$ is the domestic price index and $P_{H,t}(j)$ is the domestic price for the j^{th} good. As mentioned before, the government will be able to finance its consumption through distortionary labor taxes (τ_t) and accumulation of debt (D_t). The government budget constraint is

$$P_{H,t}G_t + E_t Q_{t,t-1} D_t = \tau_t W_t N_t + D_{t+1} \tag{38}$$

the left hand side denotes expenditures and the right hand side denotes income. W_t, N_t and $Q_{t,t+1}$ denote nominal wage, labor and the stochastic discount factor pricing the payoff of a one-period bond, respectively. For simplicity, I will assume that public debt will be bought only by domestic households in the form of national bonds. Furthermore, in order to avoid debt to behave explosively, the fiscal authority will follow fiscal rules for both government spending and labor taxes. The rules specified by equations (39) and (40) command G_t and τ_t to adjust accordingly whenever debt deviates from the steady state debt-to-GDP ratio.

$$G_t = (1-\rho_g)\, g + \rho_g G_{t-1} - (1-\rho_g)\,\gamma_g \left(\frac{D_t}{Y_t} - \frac{D}{Y}\right) \tag{39}$$

$$\tau_t = (1-\rho_\tau)\,\tau + \rho_\tau \tau_{t-1} + (1-\rho_\tau)\,\gamma_\tau \left(\frac{D_t}{Y_t} - \frac{D}{Y}\right) \tag{40}$$

where ρ_g and ρ_τ are autoregressive parameters. γ_g and γ_τ refer to the requiered rise (or fall) in G_t and τ_t to accommodate a permanent rise (or fall) in the debt-to-GDP ratio.

2.4 Monetary Authority

Since I am studying the optimal fiscal consolidation path under different monetary regimes, I will assume that the small open economy has an central bank that either follows an independent monetary policy or a currency peg.

Under the independent monetary policy, the central bank follows a domestic inflation-based Taylor rule for setting the nominal interest rate given by

$$i_t = (1-\rho_i) * i + \rho_i i_{t-1} + (1-\rho_i) * \left(\phi_\pi \left(\pi_{H,t} - \pi\right) + \phi_x \left(X_t - X\right)\right) \tag{41}$$

where $X = Y_t - Y_t^f$ is the gap between output, and the output level that will prevail if prices were flexible. If the is under a currency peg, I assume the policy rule is replaced by

$$\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} = 1 \tag{42}$$

which implies a depreciation rate equal to zero.

2.5 Market Clearing and Aggregation

2.5.1 Goods Market

The goods market clearing condition requieres that

$$Y_t(j) = C_{H,t}(j) + \int_0^1 C_{H,t}^k(j)\, dk + G_t(j) \tag{43}$$

where $C_{H,t}^k(j)\, dk$ are exports of the domestic variety j to country k. Since we are assuming identical preferences across countries, exports can be derived using equations (9), (10) and (16) but adjusting by the exchange rate

$$C_{H,t}^k(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} \left(\frac{\mathcal{E}_{i,t} P_t^k}{P_{H,t}}\right) C_t^k$$

Plugging into (43)

$$Y_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} \left[(1-\alpha)\left(\frac{P_t}{P_{H,t}}\right) C_t + \alpha \int_0^1 \left(\frac{\mathcal{E}_{i,t} P_t^k}{P_{H,t}}\right) C_t^k dk + G_t\right]$$

Plugging into the definition of aggregate domestic demand given by equation (31)

$$Y_t = S_t^{\alpha} C_t + G_t \tag{44}$$

2.5.2 Labor Market

Labor market clearing implies that labor demand will be equal to supply, therefore

$$N_t = \int_0^1 N_t(j)\, dj$$

Now, since $Y_t(j) = A_t N_t(j)$ and $Y_t(j) = \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} Y_t$

$$N_t = \frac{Y_t}{A_t} \int_0^1 \left(\frac{P_{H,t}(j)}{P_{H,t}}\right)^{-\epsilon} dj$$

which implies that output from the supply side will be given by

$$Y_t = \frac{A_t N_t}{v_t^p} \tag{45}$$

where v_t^p is term capturing price dispersion given by

$$v_t^p = \int_0^1 \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon} dj \tag{46}$$

2.5.3 Bonds Market

The bond markets clearing condition imposes that

$$B_t = B_{H,t} + B_{F,t}$$

where $B_{H,t}$ denotes domestic bonds and $B_{F,t} = \int_0^1 \mathcal{E}_{k,t-1} B_{k,t} dk$ refers to aggregate holdings of external bonds denominated in domestic currency. Moreover, since the government will be able to only hire domestic debt

$$B_{H,t} = D_t \tag{47}$$

The equilibrium allocation of foreign assets will be residually determined by the following law of motion

$$E_t \left[Q_{t,t+1} B_{F,t+1} \right] = B_{F,t} + \left(Y_t - S_t^{\alpha} C_t - G_t \right)$$

Furthermore, substituting imposing the market clearing condition for goods

$$E_t \left[Q_{t,t+1} B_{F,t+1} \right] = B_{F,t} \tag{48}$$

Which together with the assumption of zero net foreign assets implies that foreign bonds will remain at zero net supply.

2.5.4 Exogenous Shocks

The economy is subject to exogenous shocks to productivity (A_t) and global consumption (C_t^*). The stochastic processes for these two variables are given by a mean zero AR(1) in the log process

$$\ln A_t = \rho_a \ln A_{t-1} + \epsilon_t^a \tag{49}$$

$$\ln C_t^* = \rho_c \ln C_{t-1}^* + \epsilon_t^c \tag{50}$$

2.6 Parameterization and Solution Method

I solve the model using dynare and a third order approximation. All the nominal variables were rendered stationary using the transformations described in the appendix B. The model was calibrated at a quarterly frequency. Table 1 shows the structural parametres used to solve the model. All of them are standard from a small open economy and borrowed from Gali and Monacelli (2005).

Parameter	Value	Description
α	0.4	Openness
β	0.99	Discount Factor
χ	0.376	Weight of Govt Exp.in Utility Function
ϵ	6	Elast. of Substitution
ψ	1	Weight of Labor in Utility Function
ϕ	0.75	Calvo Parameter
$\phi_p i$	1.5	Inflation Coeff. Taylor Rule
ϕ_x	0.5	Output Gap Coeff. Taylor Rule
φ	3	Inverse Frisch Elasticity
ρ_a	0.66	Autocorrelation Coeff. Productivity Shock
ρ_c	0.66	Autocorrelation Coeff. Global Consumption Shock
σ_a	0.01	Std. Dev. Productivity Shock
σ_c	0.01	Std. Dev. Global Consumption Shock

Table 1: **Parameters Used to Solve the Model.**

3 Results

In this section, I discuss the potential long run benefits of debt reduction and report the results of several consolidation experiments.

3.1 The Long-Term Benefits of Consolidation

Fiscal consolidation has two faces. On one side, to reduce debt, the government must either raise taxes, decrease public spending or, both. On the other, there might be potential long-term benefits from moving towards a steady state with lower debt. Suppose that, taking as given the steady state debt-to-GDP ratio; the fiscal authority wants to choose the government spending share of output and the steady-state tax rate that maximizes flow utility for the household. In such case, the optimal decision shows that lower levels of debt are always associated with lower steady-state tax rates and higher government spending.

Moreover, as Table 2 shows, flow utility is decreasing on the steady state debt-to-GDP ratio. The welfare gains from reducing debt, in the long run, come from a higher level of consumption and public spending, and fewer hours worked. So, from the steady state utility perspective, reducing the long-term value of debt-to-GDP makes sense. Then, the relevant questions are whether it makes sense from the short-term perspective, and, given transition dynamics, what is the best path to achieve the new steady state target?

3.2 The Consolidation Experiment

To answer the above questions, I propose several consolidation experiments consisting of simulating an economy that will reduce its level of debt following an exogenously given mandate to do it. I will assume that at $t = 0$, the economy sits at a "high" level of debt. Then, at $t = 1$, an exogenous mandate is given, and the government announces a new "low" debt-to-GDP target [6]. Since the government's actions are limited by its budget constraint holding at all times, with the new debt-to-GDP target, the government is also implicitly determining the new steady state values for labor taxes and government spending.

At $t = 1$, the policy functions associated with the steady state and the steady state itself will change. At this moment, the economy will be out of its new steady state and will start converging towards it. The transition in government spending and taxes will be lead by the fiscal rules specified by equations (39) and (40). In these experiments, What I want to evaluate is how different fiscal rules will affect this transition dynamics and what effect do they have over the expected trajectory of welfare and output.

I propose three different experiments. For all of them, I will assume that the mandate is to reduce the debt-to-GDP ratio from 50 percent to 25 percent. The first experiment compares tax-based and expenditure-based consolidation plans. The second experiment proposes a more complicated analysis. Instead of an arbitrary parametrization, I will allow the fiscal authority to choose the fiscal rules that maximize the present discounted value of flow utility. In other words, I search for the parameters in the fiscal rules that yield the highest impact on welfare. Finally, in the last experiment, instead of using welfare as objective, I choose the fiscal rules that maximize the impact on output.

[6] This could also be interpreted as the IMF or the ECB impossing a new steady state debt-to-GDP target

	$\frac{D}{Y} = 2$	$\frac{D}{Y} = 1$	$\frac{D}{Y} = 0.75$	$\frac{D}{Y} = 0.5$	$\frac{D}{Y} = 0.25$	$\frac{D}{Y} = 0$
$\frac{G}{Y}$	0.3754	0.3768	0.3772	0.3775	0.3778	0.3781
S	0.5714	0.5733	0.5738	0.5743	0.5748	0.5752
Y	0.9150	0.9200	0.9212	0.9225	0.9237	0.9250
C	0.7148	0.7162	0.7166	0.7169	0.7173	0.7176
N	0.9150	0.9200	0.9212	0.9225	0.9237	0.9250
w	1.0424	1.0410	1.0407	1.0403	1.0400	1.0396
τ	0.4748	0.4643	0.4617	0.4590	0.4564	0.4537
G	0.3435	0.3467	0.3474	0.3482	0.3490	0.3497
D	1.8299	0.9200	0.6909	0.4612	0.2309	0.0000
Utility	-0.9154	-0.9139	-0.9135	-0.9131	-0.9128	-0.9124
Welfare	-91.5397	-91.3855	-91.3488	-91.3128	-91.2775	-91.2430

Table 2: **Steady States as a Function of the Debt-to-GDP Exogenous Target.**

3.2.1 Experiment 1: Revenue-based vs Expenditure-based Fiscal Consolidations

As discussed above, a large body of mostly empirical studies has found that spending-based fiscal adjustments are more likely to cause smaller recessions than tax-based fiscal adjustments. When discussing the trade-offs between the short and long run, the same literature has found evidence supporting the idea of expansionary fiscal consolidations (Alesina and Ardagna, 1998; Perotti, 1999). In this experiment, I evaluate this hypothesis by setting up fiscal rules that implement fiscal consolidations using only either taxes or public spending.

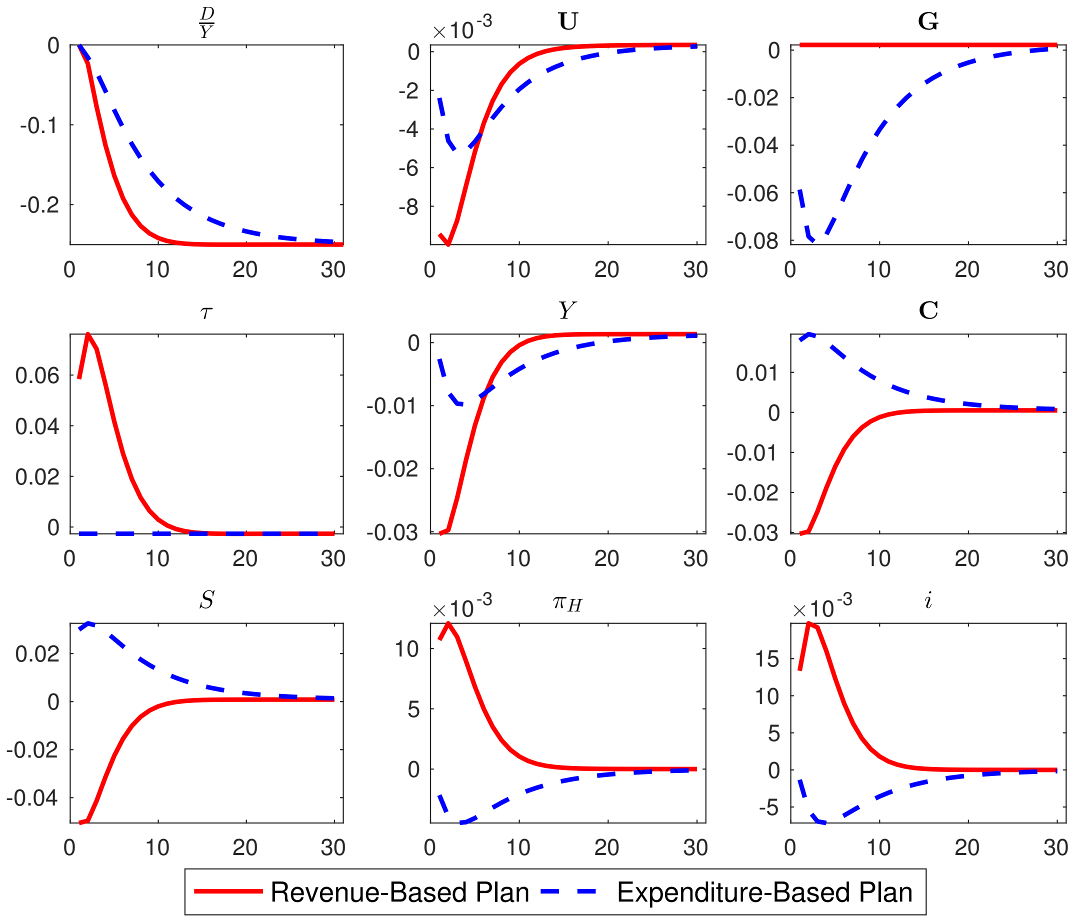

Figure 1: **Experiment 1: Debt Reduction Under Different Approaches**

In the case of the expenditure-based consolidation, I chose the parameters in the fiscal rules to be $\rho_g = \gamma_g = 0.4$ and $\rho_\tau = \gamma_\tau = 0.0$. For the revenue-based implementation, I chose $\rho_\tau = \gamma_\tau = 0.4$ and the parameters in the government spending rule to be zero. Figure 1 shows that both consolidation efforts induce a negative reaction on output. However, the recession seems to be more adverse in the case where consolidation is due thru higher taxes.

In the case, of the expenditure-based plan, output fall by less. The negative demand shock induced by the reduction of public spending promotes a real depreciation. More favorable terms of trade will give a stimulus to exports and boost total consumption yielding a more muted response of output. These results are consistent with the empirical findings of Alesina and Ardagna (1998) and Perotti (1999) in the sense that spending-based consolidations are better for output than revenue-based consolidations. However, unlike their results, fiscal consolidations are not expansionary.

3.2.2 Experiment 2: Debt Reduction, Welfare and the Monetary Regime

Recall fiscal rules given by equations (39) and (40)

$$G_t = (1-\rho_g)\, g + \rho_g G_{t-1} - (1-\rho_g)\, \gamma_g \left(\frac{D_t}{Y_t} - \frac{D}{Y} \right)$$
$$\tau_t = (1-\rho_\tau)\, \tau + \rho_\tau \tau_{t-1} + (1-\rho_\tau)\, \gamma_\tau \left(\frac{D_t}{Y_t} - \frac{D}{Y} \right)$$

In the previous experiment, I considered the case where the fiscal authority chose arbitrarily the parameters governing the rules. In this experiment, I will allow the authority to choose the government spending share of output $\left(\frac{G}{Y}\right)$ and the coefficients in the fiscal rules (ρ_τ, γ_τ, ρ_g and γ_g) that maximize welfare. The main idea is that the fiscal authority is committed to achieving the new debt-to-GDP target but can freely choose the speed and the path to achieving it. Moreover, I compare the optimal fiscal rules for two economies: one with a monetary authority following a domestic inflation-based Taylor rule (DITR regime) and another one using a currency peg (PEG).

Under the DITR regime, the fiscal authority chooses a government spending share of output equal to 0.38. The parameters in the fiscal rules are $\rho_\tau = 0.010$, $\gamma_\tau = 0.005$, $\rho_g = 0.100$ and $\gamma_g = 0.000$. Figure 2 shows that, under this regime, the authority finds optimal to implement a very gradual adjustment. The economy will converge towards the new steady state but will rely mostly on the autoregressive component of the fiscal rules to do it. By doing this, the fiscal authority is effectively neutralizing, in the present value sense, all the short term welfare losses associated with the adjustment. It is worth noting that, under an independent monetary policy regime, the welfare maximizing path commands an expenditure-based fiscal consolidation plan.

Results are somewhat different for the PEG regime. The authority chooses a government spending share of output equal to the that from the DITR regime, but the optimal coefficients are $\rho_\tau = 0.8419$, $\gamma_\tau = 0.00$, $\rho_g = 0.8361$ and $\gamma_g = 0.000$. Consolidation is achieved sooner than under the DITR but is still about 25 years after mandated. Government spending will rise straight to its new steady state value and stay there forever. Given the inability of the monetary authority to adjust the nominal interest rate or to depreciate the currency, the fiscal authority will implement a tax-based consolidation path. Increasing taxes will generate upward pressure on inflation, and will help the fiscal authority to deflate debt. Although transitory

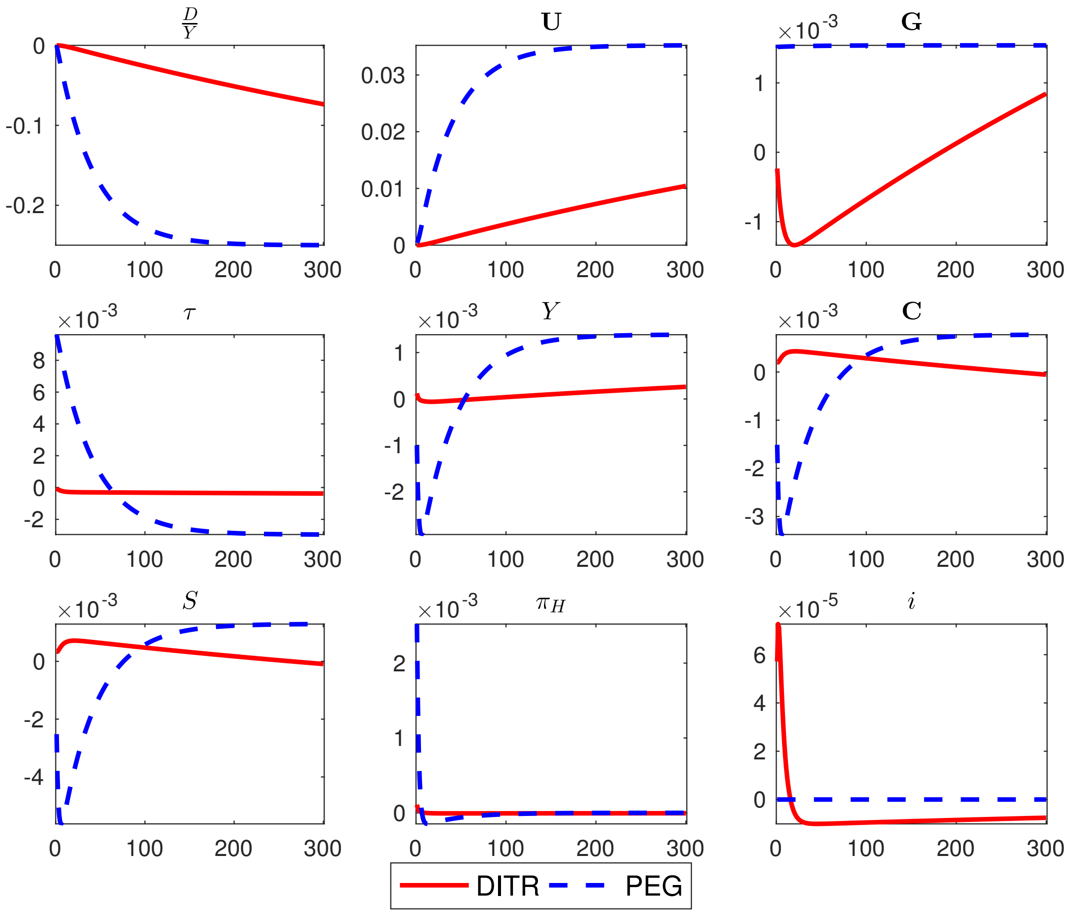

Figure 2: **Experiment 2: Debt Reduction Under the Welfare Maximizing Consolidation Path**

lower consumption and high inflation are costly for welfare, the rise in public spending and the fall in labor compensate are enough to compensate those losses.

3.2.2.1 Experiment 2a: Optimal Debt Reduction within a Fixed Deadline

Given that the fiscal authority finds optimal to gradually transition towards the new steady state debt-to-GDP target. Now, I compute the optimal path when there is a fixed deadline of 12 quarters or less to achieve it. To impose the deadline, I restrict the rule so that each parameter is constrained to the interval $0.4 \leq \lambda \leq 0.6$ where $\lambda \in \{\rho_\tau, \gamma_\tau, \rho_g, \gamma_g\}$. In this way, the authority will choose the new steady state of government spending to GDP ratio and the combination of parameters that, conditional on reaching the new target on time, will maximize the present discounted value of flow utility. .

Figure 3 shows that, as expected, the fiscal authority will reach the new target exactly by the end of the third year. The PEG achieves a slightly smaller welfare loss than the DITR thanks to the impact of domestic inflation on the debt-to-GDP ratio. Both regimes chose the same fiscal rules. Welfare is maximized by selecting a mix of higher taxes and lower public spending, and the most gradual rule possible.

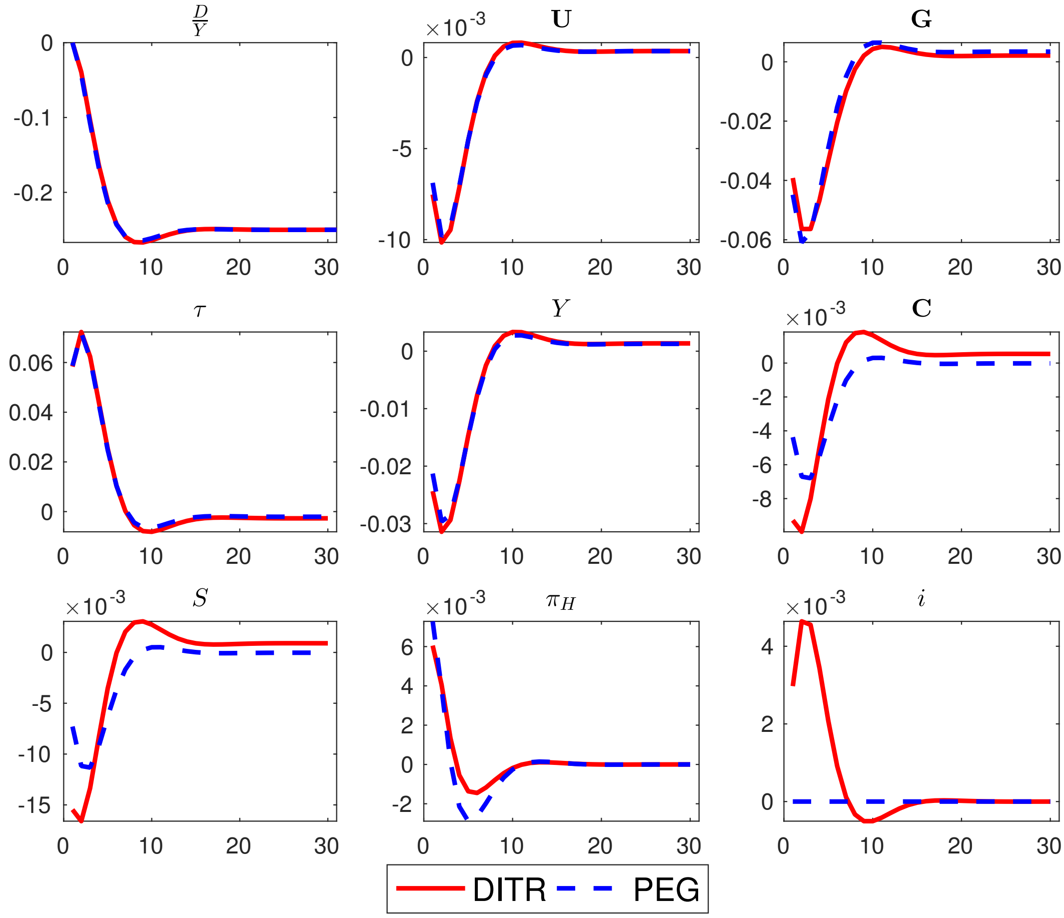

Figure 3: **Experiment 2a: Mandated Debt Reduction Within 3 Years**

Under the DITR, the fiscal authority chooses $rho_\tau = 0.4$, $\gamma_\tau = 0.4$, $\rho_g = 0.6$, $\gamma_g = -0.4$. Under the currency PEG, the optimal parameters are $rho_\tau = 0.4$, $\gamma_\tau = 0.4$, $\rho_g = 0.5$, $\gamma_g = -0.4$. Both regimes optimally choose a new government spending to GDP ratio of 0.38.

Compared with the results of Experiment 2, the welfare loss is about 1.5 percent. A significant loss since welfare is measured as the present discounted value of flow utility. Moreover, as the government's demand for goods falls and taxes increase; consumption falls enough to induce a recession that lasts about nine quarters. Under the PEG regime, the response of the terms of trade is more muted, implying that consumption does not perform as bad as in the DITR. However, this does not have a noticeable impact on the fall of output.

3.2.3 Experiment 3: Debt Reduction and Output

Having analyzed the impact on welfare, now I switch to the potential losses in output. In this experiment, I suppose the authority will choose fiscal rules that maximize the impact response of the present discounted value of output. In other words, instead of looking at welfare, the fiscal authority will search for the steady state government spending share of output and the parameters governing the fiscal rules that lead to an expansionary (or less contractionary) consolidation plan.

The first thing to notice from figure 4 is that, in contrast to the previous experiments, when maximizing the response of output, the authority optimally chooses a path that reduces debt in about two quarters. The fiscal authority will be able to minimize output losses by reducing government spending as much as possible. With lower public expenditures, the fiscal authority can afford a sharp and permanent reduction in taxes. Lower taxation stimulates consumption, and consequently, aggregate demand.

The optimal parameters in the fiscal rules for the DITR regime are $\gamma_\tau = 0.1362$, $\rho_\tau = 0.6038$, $\gamma_g = -0.0735$ and $\rho_g = 0.8371$. For the currency peg the optimal parameters are $\gamma_\tau = 0.9997$, $\rho_\tau = 0.5935$, $\gamma_g = -0.1520$ and $\rho_g = 0.9408$. Both regimes prefer a combined reaction of taxes and public spending. However, the PEG optimally chooses a path that involves a higher labor tax rate at impact.

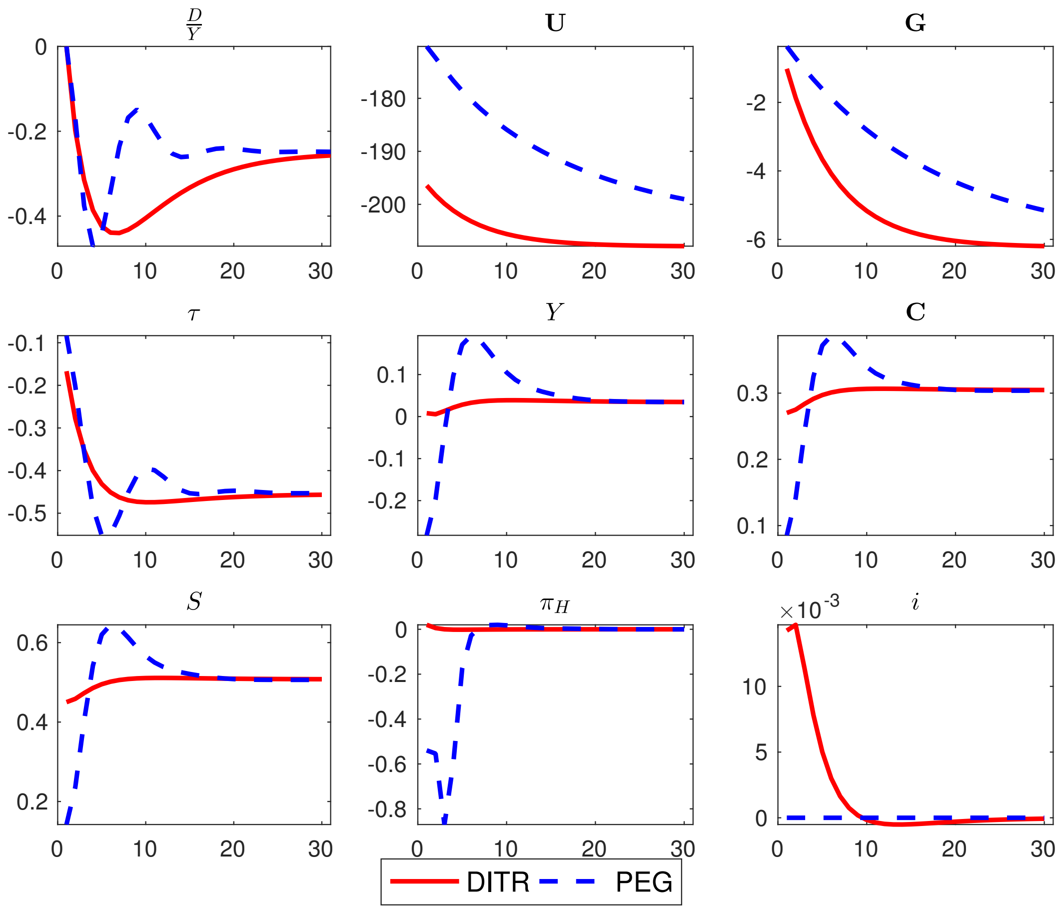

Figure 4: **Experiment 3: Debt Reduction, Output and the Optimal Consolidation Path**

In the DITR regime, the reduction in government expenditures is much steeper than in the currency PEG. The reason is that in this case, the stimulus to output is driven by the combined effect of two negative shocks coming from demand (public spending) and supply (taxes). The overall effect translates into a widening positive output gap. Since the monetary authority cares about this gap, the Taylor rule will raise the interest rate and will try to suffocate demand. In this scenario, neutralizing the reaction of the central bank requires a stronger fall in public spending.

In the currency peg, the monetary authority has no access to the interest rate and whatever happens to the output gap does not affect the peg. Also, the inability of the central bank to set the interest rate and depreciate the currency explains why the consolidation plan in the PEG is contractionary. Real depreciation under the peg is much less responsive as the exchange rate is fixed, which implies that the boost to exports is not as high as in the case where the exchange rate can depreciate freely. Under the PEG, even the optimal plan is not able to offset the output losses caused by fiscal consolidation.

4 Conclusions

Despite the global debate on fiscal imbalances and debt reduction ignited by the recent European economic crises, the current academic literature has remained silent regarding the normative properties of fiscal consolidation.

This paper has aimed to contribute to the literature by studying the optimal design of a fiscal consolidation plan and its implications for welfare and output. Furthermore, one of the objectives of this paper has been to understand the impact of conducting optimal fiscal consolidation under different monetary policy regimes.

Two important lessons are derived from the analysis presented here. First, from the output perspective, not being able to depreciate the domestic currency implies that, even the optimal fiscal consolidation plan will lead a country into economic recession. Second, from the welfare perspective, no easy option is available. Optimally, a fiscal authority would like to implement consolidation as gradually as possible, which means achieving the new debt target in a very far future. However, usually the government is constrained by a time limit, then the optimal plan will be able to reduce the welfare losses but will not completely offset them.

Some possible extensions to this paper come to mind. First, the analysis presented in this article restricts itself to the case where the government can trade only domestic debt. Then, a natural extension would be to analyze the welfare implications of fiscal consolidation when the fiscal authority can sell domestic and foreign debt. Second, as the European crisis has proven, fiscal consolidation in a monetary union is quite challenging. The quantitative framework presented here could be extended to include the perspective of a currency union. It would be interesting to study what is the optimal consolidation path for the member of a currency union and which are the possible trade-offs that arise between the member and the union as a whole.

Finally, an important caveat has to be made regarding the solution method used to solve the model. Given the highly non-linear relationship between debt, public spending, taxes, and welfare; results are quite sensitive to the order of approximation used to compute the policy functions. For instance, to a first order, the fiscal authority finds optimal to conclude consolidation as fast as possible. A result that, as proved above, does not hold to a higher order approximation. I address this caveat by estimating the model using the maximum order of approximation available in Dynare. Notwithstanding, future research could try to deal with this issue by solving the model using global solution methods.

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Appendix A Optimal Demand for a Given Variety

Since preferences are based on a Dixit-Stiglitz aggregator, we can solve the problem using two-stage budgeting. First, we will choose the mix of varieties that minimize costs, then we choose the total amount to maximize utility. To find the optimal allocation of any given expenditure within each domestic varieties we solve the static problem

$$\min_{C_{H,t}(j)} \int_0^1 P_{H,t}(j)\, C_{H,t}(j)$$
$$s.t \;\; C_{H,t} = \left[\int_0^1 C_{H,t}(j)^{\frac{\epsilon-1}{\epsilon}}\, dj\right]^{\frac{\epsilon}{\epsilon-1}}$$

After setting up the lagrangian, the first order condition is

$$P_{H,t}(j) = \lambda \left([C_{H,t}]^{\frac{1}{\epsilon-1}}\, C_{H,t}(j)^{-\frac{1}{\epsilon}} \right)$$

where λ is the lagrange multiplier. Now, without loss of generality, take any two varieties, say $\mathcal{A}$ and $\mathcal{B}$, writing equation (A) for each of them and dividing

$$\frac{C_{H,t}(\mathcal{A})}{C_{H,t}(\mathcal{B})} = \left[\frac{P_{H,t}(\mathcal{A})}{P_{H,t}(\mathcal{B})}\right]^{-\epsilon}$$

Multiply $P_{H,t}(\mathcal{A})$ and integrate both sides over all varieties

$$\int_0^1 P_{H,t}(j)\, C_{H,t}(j)\, dj = C_{H,t}(\mathcal{B})\, P_{H,t}(\mathcal{B})^{-\epsilon} \int_0^1 P_{H,t}(j)^{1-\epsilon}\, dj$$

Let domestic price index be

$$P_{H,t} = \left[\int_0^1 P_{H,t}(j)^{1-\epsilon}\, dj\right]^{\frac{1}{1-\epsilon}}$$

And define total expenditures on domestic goods as

$$P_{H,t}C_{H,t} = \int_0^1 P_{H,t}(j)\, C_{H,t}(j) dj$$

Therefore, we can transform (A) into

$$P_{H,t}C_{H,t} = \frac{C_{H,t}(j)}{P_{H,t}(j)^{-\epsilon}} \int_0^1 P_{H,t}(j)^{1-\epsilon}\, dj$$
$$P_{H,t}C_{H,t} = \frac{C_{H,t}(j)}{P_{H,t}(j)^{-\epsilon}} P_{H,t}^{1-\epsilon}$$

So that, the demand function for each domestic variety is proportional to its relative price and total consumption of domestic goods

$$C_{H,t}(j) = \left[\frac{P_{H,t}(j)}{P_{H,t}}\right]^{-\epsilon} C_{H,t} \quad \forall\, i,\, j \in [0,\, 1]$$

Appendix B Inflation and Price Dispertion

As shown before, the domestic price level is defined in terms of the j^{th} variety. To get rid of this heterogeneity, I will use the Calvo (1983) assumption and rewrite all the remaining equilibrium conditions that involve prices. Given that a fraction $(1-\phi)$ of domestic firms will update their price each period, equation (8) can be written as

$$P_{H,t}^{1-\epsilon} = \int_0^{1-\phi} \left(p_{H,t}^{\#}\right)^{1-\epsilon} dj + \int_{1-\phi}^{1} P_{t-1}^{1-\epsilon}(j)\, dj \tag{51}$$

$$P_{H,t}^{1-\epsilon} = \left(P_{H,t}^{\#}\right)^{1-\epsilon} + \phi P_{t-1}^{1-\epsilon} \tag{52}$$

Dividing both sides by $P_{H,t-1}^{1-\epsilon}$,

$$(1+\pi_{H,t})^{1-\epsilon} = (1-\phi)\left(1+\pi_t^{\#}\right)^{1-\epsilon} + \phi \tag{53}$$

where $\pi_{H,t}^{\#} = \left(\frac{P_{H,t}^{\#}}{P_{H,t-1}} - 1\right)$ is the reset price inflation. In its turn, the reset price defined by equation (33) can be written as

$$\frac{P_{H,t}^{\#}}{P_{H,t-1}} = \frac{\epsilon}{\epsilon-1}\frac{1}{P_{H,t-1}}\frac{X_{1,t}}{X_{2,t}} \tag{54}$$

Now, from equations (34) and (35),

$$\chi_{1,t} = u'(C_t)\, mc_t Y_t + \phi\beta E_t \chi_{1,t+1}\left(\frac{P_{H,t+1}}{P_{H,t}}\right)^{\epsilon} \tag{55}$$

$$\chi_{2,t} = u'(C_t)\, Y_t + \phi\beta E_t \chi_{2,t+1}\left(\frac{P_{H,t+1}}{P_{H,t}}\right)^{\epsilon-1} \tag{56}$$

where $\chi_{1,t} = \frac{X_{1,t}}{P_{H,t}^{\epsilon}}$ and $\chi_{2,t} = \frac{X_{2,t}}{P_{H,t}^{\epsilon-1}}$. Substituting into (54)

$$1+\pi_{H,t}^{\#} = \frac{\epsilon}{\epsilon-1}(1+\pi_{H,t})\frac{\chi_{1,t}}{\chi_{2,t}} \tag{57}$$

Calvo's principle can also be applied to the price dispersion

$$v_t^p = \int_0^{1-\phi} \left(\frac{P_{H,t}^{\#}}{P_{H,t}} \right)^{-\epsilon} dj + \int_{1+\phi}^{1} \left(\frac{P_{H,t}(j)}{P_{H,t}} \right)^{-\epsilon} dj \tag{58}$$

Multypling and dividing by $P_{H,t-1}^{-\epsilon}$

$$v_t^p = (1-\phi) \left(1 + \pi_t^{\#} \right)^{-\epsilon} (1 + \pi_{H,t})^{\epsilon} + (1 + \pi_{H,t})^{-\epsilon} \phi v_{t-1}^p \tag{59}$$