INTERNATIONAL DEBT DELEVERAGING

Luca Fornaro
CREI, Universitat Pompeu Fabra and
Barcelona GSE

Abstract
This paper provides a framework to understand the adjustment triggered by an episode of debt deleveraging among financially integrated countries. During a period of international deleveraging, world consumption demand is depressed and the world interest rate is low, reflecting a high propensity to save. If exchange rates are allowed to float, deleveraging countries can rely on depreciations to increase production and mitigate the fall in consumption associated with debt reduction. The key insight of the paper is that in a monetary union this channel of adjustment is shut off, because deleveraging countries cannot depreciate against the other countries in the monetary union, and therefore the fall in the demand for consumption and the downward pressure on the interest rate are amplified. As a result, deleveraging in a monetary union can generate a liquidity trap and an aggregate recession. For instance, the model predicts that international deleveraging by peripheral euro area countries can account for around 24% of the output loss experienced by the euro area in the two years following the 2008 financial crisis. (JEL: E52, F41, F45, G15.)

1. Introduction

Episodes of global debt deleveraging are rare, but when they occur they come with deep recessions and destabilize the international monetary system. Back during the Great Depression of the 1930s the world entered a period of global debt reduction and experienced the most severe recession in modern history. The cornerstone of the international monetary system, the Gold Standard, came under stress and was

---

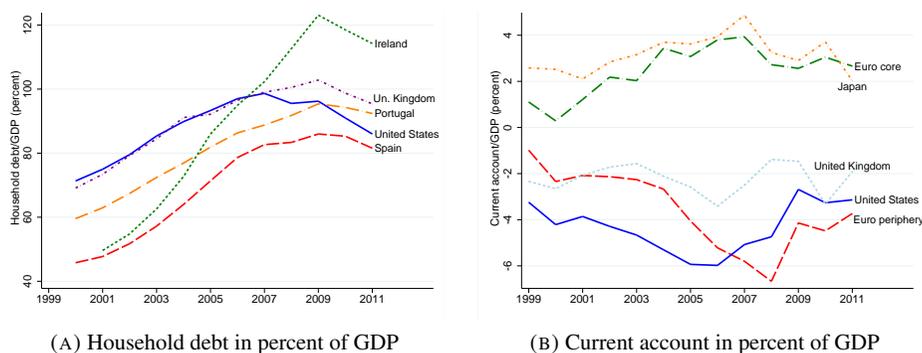(A) Household debt in percent of GDP   (B) Current account in percent of GDP

FIGURE 1. Motivating facts. Notes: the left panel illustrates the fall in private debt characterizing the US, the UK and the euro area periphery in the aftermath of the 2008 financial crisis. The right panel shows that deleveraging has been accompanied by improvements in the current account, especially in the case of euro area peripheral countries. It also illustrates the contemporaneous fall in the current account surplus of creditor countries, here captured by core euro area countries and Japan. Data are from Eurostat and the OECD.

abandoned in 1936, when the remaining countries belonging to the Gold Block gave up their exchange rate pegs against gold. Almost 80 years later, history seems to be repeating itself. Following the 2007-2008 turmoil in financial markets several countries experienced sudden stops in capital inflows and embarked in a process of private debt deleveraging (Figure 1), accompanied by a deep economic downturn, the Great Recession. Once again, the status quo in the international monetary system has been challenged, and this time the survival of the euro area, in which deleveraging by peripheral countries has been associated with a deep and prolonged recession, has been called into question.[1] These events suggest that fixed exchange arrangements, such as monetary unions, are hard to maintain during times of global debt deleveraging. But more research is needed to understand exactly why this is the case.

This paper provides a novel framework to understand the adjustment triggered by an episode of debt deleveraging among financially integrated countries, and particularly the role played by the exchange rate regime. The model features a continuum of small open economies trading with each other. Each economy is inhabited by households which participate in financial markets to smooth the impact of temporary income shocks on consumption, in the spirit of the Bewley (1977) closed economy model. Foreign borrowing and lending arise endogenously as households use the international credit markets to insure against country-specific productivity shocks. Crucially, each household is subject to an exogenous borrowing limit. I study the response of the world economy to a *deleveraging shock*, which consists in a permanent

---

1. See chapter 3 of Eichengreen (1998) on the Gold Standard crisis during the Great Depression. McKinsey (2010, 2012) describe the private debt deleveraging process in the aftermath of the 2008 global financial crisis. Lane (2012) and Shambaugh (2012) are two excellent sources on the euro area crisis.

tightening of the borrowing limit. The model cannot be solved analytically, and I analyse its properties through simulations of a deleveraging event that captures some salient features of the euro area adjustment to the 2008 global financial crisis.

I start by considering a baseline economy in which the only frictions present are the borrowing limit and incomplete financial markets. The first result is that the process of debt reduction generates a fall in the world interest rate, which overshoots its long run value. The drop in the world interest rate is due to two different effects. On the one hand, the most indebted countries are hit by a sudden stop in capital inflows and are forced to increase savings, in order to reduce their debt and satisfy the new borrowing limit. On the other hand, the countries starting with a low stock of debt, as well as those starting with a positive stock of foreign assets, want to increase precautionary savings as a buffer against the risk of hitting the borrowing limit in the future. Both effects lower global consumption demand and generate a rise in the propensity to save. As a consequence, the world interest rate falls to guarantee that the rest of the world absorbs the forced savings of high-debt borrowing-constrained economies.

In the baseline model, deleveraging also affects the supply side of the economy. In fact, high-debt countries respond to the deleveraging shock by increasing their production of tradable goods, so as to repay their external debt without cutting consumption too severely. The opposite occurs in the rest of the world, which experiences a contraction in the production of tradable goods. This process redistributes income from wealthy countries, characterized by a low propensity to consume, toward high-debt borrowing-constrained countries, featuring a high propensity to consume. Hence, the supply-side response to the deleveraging shock mitigates the fall in global consumption demand, and consequently the drop in the world interest rate.

Importantly, in order for the supply-side adjustment to take place, real wages need to fall in high-debt countries and rise in the rest of the world. A large body of evidence, however, suggests that nominal wages adjust slowly to shocks. In particular nominal wages do not fall much during deep recessions, in spite of sharp rises in unemployment.[2] To understand the implications of this friction, I then turn to a model in which nominal wages are partially rigid.

With nominal wage rigidities, monetary policy and the exchange rate regime affect the response of real variables to the deleveraging shock. I find that when exchange rates are flexible, and monetary policy stabilizes CPI inflation, the adjustment to

---

[2]. In their empirical studies, Eichengreen and Sachs (1985) and Bernanke and Carey (1996) find that nominal wage rigidities contributed substantially to the fall in output during the Great Depression, in particular among countries belonging to the Gold Block. More recently, Schmitt-Grohé and Uribe (2016) have documented the importance of nominal wage rigidities in the context of the 2001 Argentine crisis and of the Great Recession in countries at the euro area periphery. Another strand of the literature shows the relevance of nominal wage rigidities using micro data. For example, Fehr and Goette (2005), Gottschalk (2005) and Barattieri et al. (2014) use worker-level data to show that changes in nominal wages, especially downward, happen infrequently. Fabiani et al. (2010) obtain similar results using firm-level data from several European countries.

deleveraging is essentially identical to the one occurring in the baseline model with flexible wages. In fact, under flexible exchange rates the fall in real wages in high-debt countries is attained with a nominal exchange rate depreciation. Conversely, countries in the rest of the world experience a nominal exchange rate appreciation which leads to an increase in real wages. But in a monetary union exchange rates between members are fixed, and the adjustment in real wages cannot be achieved through movements in the nominal exchange rate. Indeed, when I consider a world in which all countries belong to a single monetary union, and in which monetary policy stabilizes average CPI inflation, I find that the production response to the deleveraging shock is essentially muted. Thus, in a monetary union households living in high-debt countries have to reduce their debt mainly by decreasing consumption. The deep fall in consumption demand coming from high-debt countries amplifies the increase in the propensity to save and the downward pressure on the interest rate. The result is that during deleveraging the drop in the world interest rate is much larger in a monetary union, compared to the economy with flexible exchange rates.

In the last part of the paper I focus on a monetary union, and study the impact of deleveraging on output and welfare. First, I show that plausible values of the deleveraging shock give rise to quantitatively relevant union-wide recessions. This happens because, following the deleveraging shock, monetary policy ends up being constrained by the zero lower bound on the nominal interest rate. Since the interest rate cannot fall enough to guarantee market clearing at the central bank's inflation target, firms decrease prices in order to eliminate excess supply. Given the sticky nominal wages, the fall in prices translates into a rise in real wages that reduces employment and production. Thus, during deleveraging the monetary union enters a liquidity trap, characterized by a deflationary recession. Interestingly, drops in output, policy rate and price inflation, and a rise in real wages are all salient features of the recession experienced by the euro area in the aftermath of the 2008 financial crisis. Quantitatively, the benchmark deleveraging shock, which generates a fall in capital inflows toward high-debt countries similar to the one experienced in 2009 by peripheral euro area countries, produces over two years a cumulated fall in the output of the whole monetary union equal to 10% of quarterly steady state production. For comparison, I estimate the output loss experienced by the euro area between 2008Q4 and 2010Q3 to be around 41.7% of 2008Q3 GDP per capita. Hence, under the benchmark parametrization, the model captures around 24% of the output loss experienced by the euro area following the 2008 financial crisis. The recession hits high-debt countries particularly hard, but the economic downturn also spreads to the countries that are not financially constrained. I also show that the frictions associated with participation in a monetary union generate substantial welfare losses during deleveraging, especially in high-debt countries.

Finally, I discuss policy interventions that mitigate the recession during deleveraging in a monetary union. First, I show that a higher inflation target mitigates the fall in output during deleveraging. Indeed, when the nominal interest rate hits the zero bound the real interest rate is equal to the inverse of expected inflation, so that a higher inflation target implies a lower real interest rate, which stimulates

consumption demand and production. Second, I consider the impact of transfers from creditor to debtor countries. Since debtor countries have a higher propensity to consume out of income that creditors, the transfers stimulate aggregate demand and limit the drop in output during deleveraging. I show that both policy interventions have a positive impact on aggregate welfare. However, in both cases the welfare gains are unevenly distributed across countries. In fact, while high-debt financlally-constrained economies enjoy large welfare gains from both policy interventions, wealthy countries suffer welfare losses.

This paper is related to several strands of the literature. First, the paper is about deleveraging and liquidity traps. Recently, Guerrieri and Lorenzoni (2017) and Eggertsson and Krugman (2012) have drawn a connection between deleveraging and drops in the interest rate in closed economies, while the focus of this paper is on the international dimension of a deleveraging episode. Deleveraging in open economies is also studied by Martin and Philippon (2017) and Benigno and Romei (2014). Martin and Philippon (2017) provide a rich framework to study the dynamics of euro area countries around the 2008 financial crisis, with particular attention to the behavior of private and public debt. Their analysis considers the relative performance of single countries with respect to the euro area average, while the focus of this paper is on the aggregate, union-wide, impact of deleveraging. Benigno and Romei (2014) study a global liquidity trap triggered by deleveraging in a two-country model. Their main focus is on the equilibrium reached under the cooperative optimal policy when exchange rates are flexible. Instead, here the focus is on the constraints on the macroeconomic adjustment to deleveraging imposed by participation in a monetary union. Moreover, compared to the standard two-country model studied by Benigno and Romei (2014), the model proposed by this paper captures the rise in precautionary savings triggered by the deleveraging shock,[3] and allows for the study of the heterogenous impact of deleveraging on output and welfare across countries member of the monetary union.[4]

Second, the paper is related to the literature studying exchange rate policy during financial crises. Some examples of this literature are Cespedes et al. (2004), Christiano et al. (2004), Cook (2004), Devereux et al. (2006), Braggion et al. (2007), Gertler et al. (2007), Schmitt-Grohé and Uribe (2016), Fornaro (2015) and Ottonello (2013). While all these papers study a single small open economy that takes the world interest rate as given, my paper contributes to this literature by considering a global economy in which the endogenous determination of the world interest rate is crucial.[5]

---

3.   In their empirical analysis, Mody et al. (2012) show that the precautionary savings motive has been an important driver of the increase in household saving rates occurred across advanced economies in the aftermath of the 2008 financial crisis.

4.   Another difference is that in Benigno and Romei (2014) nominal rigidities prevent the adjustment in the terms of trade. Instead, here nominal rigidities impede the reallocation of production between tradable and non-tradable goods. These are two complementary adjustment mechanisms.

5.   The current events in the Eurozone have revived the literature on the macroeconomic management of monetary unions. Recent contributions build on the multi-country framework developed by Galí and

The paper also relates to the literature studying precautionary savings in incomplete-market economies with idiosyncratic shocks. The literature includes the seminal works of Bewley (1977), Huggett (1993) and Aiyagari (1994), who consider closed economies in which consumers borrow and lend to self-insure against idiosyncratic income shocks. Guerrieri and Lorenzoni (2017) use a Bewley model to study the impact of deleveraging on the interest rate in a closed economy. My paper shares with their work the focus on precautionary savings. Starting from Clarida (1990), some authors have used multi-country models with idiosyncratic shocks and incomplete markets to study international capital flows. Examples are Castro (2005), Bai and Zhang (2010) and Chang et al. (2013). This is the first paper that employs a multi-country Bewley model to study the interactions between deleveraging, the exchange rate regime and liquidity traps.

From an empirical perspective, this paper is linked to the work of Lane and Milesi-Ferretti (2012), who look at the adjustment in the current account balances during the Great Recession. They find that the compression in the current account deficits was larger for those countries that were relying more heavily on external financing before the crisis. Moreover, they find that most of the adjustment passed through a compression in domestic demand, contributing to the severity of the crisis in deficit countries. My model rationalizes these facts. This paper also speaks to the empirical findings of Mian et al. (2013) and Mian and Sufi (2014). These authors find that the fall in consumption and employment in the US during the 2008-2009 recession was stronger in those counties where the pre-crisis expansion in credit driven by the rise in house prices was more pronounced. This evidence is consistent with the results of my paper, if the monetary union version of the model is interpreted as a large country composed of many different regions.

The rest of the paper is structured as follows. Section 2 introduces the baseline model and briefly analyzes the steady state. Section 3 considers the adjustment following a deleveraging shock in the baseline model. Section 4 describes the response to a deleveraging shock in a model with nominal wage rigidities. Section 5 highlights the role of the zero lower bound in translating a deleveraging episode into a recession in a monetary union, and presents some policy experiments. Section 6 concludes.

2. Baseline model

I start by studying a baseline model in which the only frictions present are located in the financial markets. This simple model is useful to obtain intuition about some crucial channels of adjustment triggered by the deleveraging shock. It will also serve

---

Monacelli (2005). Examples are Farhi and Werning (2017), who look at the optimal management of fiscal policy in a monetary union, and Farhi et al. (2014), who derive a set of fiscal measures able to substitute for exchange rate flexibility inside a currency union. Instead, Benigno (2004) uses a two-country model to study monetary unions. These frameworks abstract from financial frictions, a key element in my analysis.

as a comparison benchmark for the, more realistic, model with nominal wage rigidities studied in Section 4.

Consider a world composed of a continuum of measure one of small open economies indexed by $i \in [0,1]$. Each economy can be thought of as a country.[6] Time is discrete and indexed by t. Each country is populated by a continuum of measure one of identical infinitely lived households and by a large number of firms. All economies produce two consumption goods: a homogeneous tradable good and a non-tradable good. Countries face idiosyncratic shocks in their production technologies, while the world economy has no aggregate uncertainty. Households borrow and lend on the international credit markets in order to smooth the impact of productivity shocks on consumption. There is an exogenous limit on how much each household can borrow. I start by analyzing the steady state of the model, in which the borrowing limit is held constant. The next section studies the transition after an unexpected shock that tightens the borrowing limit.

Households. Households derive utility from consumption $C_{i,t}$ and experience disutility from labor effort $L_{i,t}$. The expected lifetime utility of the representative household in a generic country i is

$$E_0 \left[\sum_{t=0}^{\infty} \beta^t \left(\frac{C_{i,t}^{1-\gamma} - 1}{1 - \gamma} - \frac{L_{i,t}^{1+\psi}}{1 + \psi} \right) \right], \tag{1}$$

with $\gamma \geq 1$ and $\psi \geq 0$. In this expression, $E_t[\cdot]$ is the expectation operator conditional on information available at time t and $0 < \beta < 1$ is the subjective discount factor. The period utility function is separable in consumption and labor effort, as it is commonly assumed in the literature on monetary economics (Galí, 2009). Consumption is a Cobb-Douglas aggregate of a tradable good $C_{i,t}^T$ and a non-tradable good $C_{i,t}^N$

$$C_{i,t} = \left(C_{i,t}^T \right)^{\omega} \left(C_{i,t}^N \right)^{1-\omega},$$

where $0 < \omega < 1$.

Each household can trade in one period risk-free bonds. Bonds are denominated in units of the tradable consumption good and pay the gross interest rate R_t. The interest rate is common across countries, and hence R_t can be interpreted as the world interest rate.

There are no trade frictions and the price of the tradable good is the same in every country. Normalizing the price of the traded good to 1, the household budget constraint expressed in units of the tradable good is

$$C_{i,t}^T + p_{i,t}^N C_{i,t}^N + \frac{B_{i,t+1}}{R_t} = w_{i,t} L_{i,t} + B_{i,t} + \Pi_{i,t}. \tag{2}$$

---

6. Another possibility is to think of an economy as a region inside a large country, for example a US state or county.

The left-hand side of this expression represents the household's expenditure. $p_{i,t}^N$ denotes the price of a unit of non-tradable good in terms of the tradable good in country i.[7] Hence, the term $C_{i,t}^T + p_{i,t}^N C_{i,t}^N$ is the total expenditure of the household in consumption expressed in units of the tradable good. $B_{i,t+1}$ denotes the purchase of bonds made by the household at time t at price $1/R_t$. If $B_{i,t+1} < 0$ the household is a borrower.

The right-hand side captures the household's income. $w_{i,t} L_{i,t}$ is the household's labor income. Labor is immobile across countries and hence the wage $w_{i,t}$ is country-specific. $B_{i,t}$ is the gross return on investment in bonds made at time $t-1$. Finally, $\Pi_{i,t}$ denotes the total profits received from firms. All domestic firms are wholly owned by domestic households and equity holdings within these firms are evenly divided among them.

There is a limit on how much each household is able to borrow. In particular, debt repayment cannot exceed the exogenous limit κ_t, so that the bond position has to satisfy[8]

$$B_{i,t+1} \geq -\kappa_t. \tag{3}$$

This constraint captures in a simple form a case in which a household cannot credibly commit in period t to repay more than κ_t units of the tradable good to its creditors in period $t+1$.[9]

The household's optimization problem is to choose a sequence $\{C_{i,t}^T, C_{i,t}^N, L_{i,t}, B_{i,t+1}\}_{t \geq 0}$ to maximize the expected present discounted value of utility (1), subject to the budget constraint (2) and the borrowing limit (3), taking the initial bond holdings $B_{i,0}$, prices $\{R_t, p_{i,t}^N, w_{i,t}\}_{t \geq 0}$, and the path for the borrowing limit $\{\kappa_t\}_{t \geq 0}$ as given. The household's first-order conditions can be written as

$$p_{i,t}^N = \frac{1-\omega}{\omega} \frac{C_{i,t}^T}{C_{i,t}^N} \tag{4}$$

$$L_{i,t}^\psi = w_{i,t} \lambda_{i,t} \tag{5}$$

$$\frac{\lambda_{i,t}}{R_t} = \beta E_t [\lambda_{i,t+1}] + \mu_{i,t} \tag{6}$$

$$B_{i,t+1} \geq -\kappa_t, \quad \text{with equality if } \mu_{i,t} > 0, \tag{7}$$

where $\lambda_{i,t} \equiv \omega C_{i,t}^{1-\gamma}/C_{i,t}^T$ denotes the marginal utility from consumption of the tradable good, while $\mu_{i,t}$ is the non-negative Lagrange multiplier associated with the borrowing limit. The optimality condition (4) equates the marginal rate of substitution of the two

---

7. $p_{i,t}^N$ is not necessarily equalized across countries because the non-traded good is, by definition, not traded internationally.

8. Throughout the analysis I assume that the exogenous borrowing limit κ_t is tighter than the natural borrowing limit.

9. In reality tight access to credit may manifest itself through high interest rates, rather than through a quantity restriction on borrowing. In Online Appendix A I show that it is possible to recast the borrowing limit (3) in terms of positive spreads over the world interest rate without changing any of the results.

consumption goods, tradables and non-tradables, to their relative price. Equation (5) is the optimality condition for labor supply. Equation (6) is the Euler equation for bonds. When it binds, the borrowing constraint generates a wedge between the marginal utility from consuming in the present and the marginal utility from consuming next period, given by the shadow price of relaxing the borrowing constraint $\mu_{i,t}$. Finally, equation (7) is the complementary slackness condition associated with the borrowing limit.

Firms. Firms rent labor from households and produce both consumption goods, taking prices as given. Each sector is populated by a continuum of measure one of identical firms. A typical firm in the tradable sector in country i maximizes profits

$$\Pi_{i,t}^{T} = Y_{i,t}^{T} - w_{i,t}L_{i,t}^{T},$$

where $Y_{i,t}^{T}$ is the output of tradable good and $L_{i,t}^{T}$ is the amount of labor employed by the firm. The production function is

$$Y_{i,t}^{T} = A_{i,t}^{T}\left(L_{i,t}^{T}\right)^{\alpha_{T}},$$

where $0 < \alpha_{T} < 1$.[10] $A_{i,t}^{T}$ determines labor productivity in the tradable sector. Profit maximization implies

$$\alpha_{T}A_{i,t}^{T}\left(L_{i,t}^{T}\right)^{\alpha_{T}-1} = w_{i,t}.$$

This expression says that at the optimum firms equalize the marginal profit from an increase in labor, the left-hand side of the expression, to the marginal cost, the right-hand side.

Similarly, firms in the non-tradable sector maximize profits

$$\Pi_{i,t}^{N} = p_{i,t}^{N}Y_{i,t}^{N} - w_{i,t}L_{i,t}^{N},$$

where Y_{i}^{N} is the output of non-tradable good and $L_{i,t}^{N}$ is the amount of labor employed in the non-tradable sector. Labor is perfectly mobile across sectors within a country and hence firms in both sectors pay the same wage $w_{i,t}$. The production function available to firms in the non-tradable sector is

$$Y_{i,t}^{N} = A_{i,t}^{N}\left(L_{i,t}^{N}\right)^{\alpha_{N}},$$

where $0 < \alpha_{N} < 1$. The term $A_{i,t}^{N}$ determines the productivity of firms in the non-tradable sector. The optimal choice of labor in the non-tradable sector implies

$$p_{i,t}^{N}\alpha_{N}A_{i,t}^{N}\left(L_{i,t}^{N}\right)^{\alpha_{N}-1} = w_{i,t}.$$

---

10. To introduce constant returns-to-scale in production we can assume a production function of the form $Y_{i,t}^{T} = A_{i,t}^{T}\left(L_{i,t}^{T}\right)^{\alpha_{T}}K^{1-\alpha_{T}}$, where K is a fixed production factor owned by the firm, for example physical or organizational capital. The production function in the main text corresponds to the normalization $K = 1$.

Just as firms in the tradable sector, at the optimum firms in the non-tradable sector equalize the marginal benefit from increasing employment to its marginal cost.[11]

Every period countries are hit by idiosyncratic shocks to their labor productivity. Specifically, both $A_{i,t}^T$ and $A_{i,t}^N$ are stochastic and follow Markov processes. These shocks are the source of idiosyncratic uncertainty that gives rise to cross-country financial flows in steady state.

Market clearing. Since households inside a country are identical, we can interpret equilibrium quantities as either household or country specific. For instance, the end-of-period net foreign asset position of country i is equal to the end-of-period holdings of bonds of the representative household divided by the world interest rate[12]

$$NFA_{i,t} = \frac{B_{i,t+1}}{R_t}.$$

Market clearing for the non-tradable consumption good requires that in every country consumption is equal to production, that is $C_{i,t}^N = Y_{i,t}^N$. Moreover, equilibrium on the labor market implies that in every country the labor supplied by the households is equal to the labor demanded by firms, $L_{i,t} = L_{i,t}^T + L_{i,t}^N$.

These two market clearing conditions, in conjunction with the budget constraint of the household, as well as with the equilibrium condition $\Pi_{i,t} = \Pi_{i,t}^T + \Pi_{i,t}^N$, give the market clearing condition for the tradable consumption good in country i

$$C_{i,t}^T = Y_{i,t}^T + B_{i,t} - \frac{B_{i,t+1}}{R_t}.$$

This expression can be rearranged to obtain the law of motion for the stock of net foreign assets owned by country i, i.e. the current account

$$NFA_{i,t} - NFA_{i,t-1} = CA_{i,t} = Y_{i,t}^T - C_{i,t}^T + B_{i,t}\left(1 - \frac{1}{R_{t-1}}\right).$$

As usual, the current account is given by the sum of net exports, $Y_{i,t}^T - C_{i,t}^T$, and net interest payments on the stock of net foreign assets owned by the country at the start of the period, $B_{i,t}(1 - 1/R_{t-1})$.

Finally, in every period the world consumption of the tradable good has to be equal to the world production, $\int_0^1 C_{i,t}^T \, di = \int_0^1 Y_{i,t}^T \, di$. This equilibrium condition implies that bonds are in zero net supply at the world level, $\int_0^1 B_{i,t+1} \, di = 0$.

2.1. Equilibrium

Given a sequence of the world interest rate $\{R_t\}_{t \geq 0}$ and of the borrowing limit $\{\kappa_t\}_{t \geq 0}$, define the period t optimal decisions of the household as $C_t^T\left(B, A^T, A^N\right)$,

---

11.   Throughout the paper I focus on equilibria in which production always occurs in both sectors. Given the functional forms assumed, it is indeed optimal for firms to always operate in both sectors.

12.   I follow the convention of netting interest payments out of the net foreign asset position.

$C_t^N\left(B,A^T,A^N\right)$ and $L_t\left(B,A^T,A^N\right)$, the period t optimal labor demand decisions as $L_t^T\left(B,A^T,A^N\right)$ and $L_t^N\left(B,A^T,A^N\right)$, and the period t equilibrium prices $w_t\left(B,A^T,A^N\right)$ and $p_t^N\left(B,A^T,A^N\right)$, in a country with bond holdings $B_{it}=B$ and productivities $A_{i,t}^T=A^T$ and $A_{i,t}^N=A^N$. Notice that these decision rules fully determine the transition for bond holdings.

Define $\Psi_t\left(B,A^T,A^N\right)$ as the joint distribution of bond holdings and current productivities across countries. The optimal decision rules for bond holdings together with the process for productivities yield a transition probability for the country-specific states $\left(B,A^T,A^N\right)$. This transition probability can be used to compute the next period distribution $\Psi_{t+1}\left(B,A^T,A^N\right)$, given the current distribution $\Psi_t\left(B,A^T,A^N\right)$. We can now define an equilibrium.

DEFINITION 1. *An equilibrium is a sequence of the world interest rate* $\{R_t\}_{t\geq 0}$, *a sequence of pricing functions* $\{w_t\left(B,A^T,A^N\right),p_t^N\left(B,A^T,A^N\right)\}_{t\geq 0}$, *a sequence of policy rules* $\{C_t^T\left(B,A^T,A^N\right),\ C_t^N\left(B,A^T,A^N\right),\ L_t\left(B,A^T,A^N\right),\ L_t^T\left(B,A^T,A^N\right),\ L_t^N\left(B,A^T,A^N\right)\}_{t\geq 0}$, *and a sequence of joint distributions for bond holdings and productivity* $\{\Psi_t\left(B,A^T,A^N\right)\}_{t\geq 0}$, *such that given the initial distribution* $\Psi_0\left(B,A^T,A^N\right)$ *and a sequence of the borrowing limit* $\{\kappa_t\}_{t\geq 0}$

- $C_t^T\left(B,A^T,A^N\right),C_t^N\left(B,A^T,A^N\right),L_t\left(B,A^T,A^N\right),L_t^T\left(B,A^T,A^N\right),L_t^N\left(B,A^T,A^N\right)$ *satisfy households' and firms' optimality conditions.*
- *Markets for consumption and labor clear in every country*

$$\frac{B_{t+1}\left(B,A^T,A^N\right)}{R_t}=A^T\left(L_t^T\left(B,A^T,A^N\right)\right)^{\alpha_T}-C_t^T\left(B,A^T,A^N\right)+B$$

$$C_t^N\left(B,A^T,A^N\right)=A^N\left(L_t^N\left(B,A^T,A^N\right)\right)^{\alpha_N}$$

$$L_t\left(B,A^T,A^N\right)=L_t^T\left(B,A^T,A^N\right)+L_t^N\left(B,A^T,A^N\right).$$

- $\Psi_t\left(B,A^T,A^N\right)$ *is consistent with the decision rules.*
- *The market for bonds clears at the world level*

$$\int B\,\mathrm{d}\Psi_t\left(B,A^T,A^N\right)=0.$$

2.2. Parameters

The model cannot be solved analytically and I analyze its properties using numerical simulations. I employ a global solution method in order to deal with the nonlinearities involved by a large shock such as the deleveraging shock studied in the next section. Online Appendix B describes the numerical solution method.

One period corresponds to one quarter. The risk aversion is set to $\gamma=2$, a standard value. The discount factor is set to $\beta=0.9938$ in order to match an annualized real interest rate in the initial steady state of 2.5%. This is meant to capture the low interest rate environment characterizing the US and the euro area in the years preceding the

TABLE 1. Parameters.

	Value	Source/Target
Risk aversion	$\gamma = 2$	Standard value
Discount factor	$\beta = 0.9938$	$R = 1.025$ (annual)
Frisch elasticity of labor supply	$1/\psi = 1/2.2$	Galí and Monacelli (2016)
Share of tradables in consumption	$\omega = 0.2$	Estimate for the euro area
Labor share in tradable sector	$\alpha_T = 0.65$	Estimate for the euro area
Labor share in non-tradable sector	$\alpha_N = 0.65$	Estimate for the euro area
Productivity process	$\sigma_A = 0.024, \rho = 0.92$	Estimate for the euro area
Initial borrowing limit	$\kappa = 4.56$	World debt/GDP $= 21\%$ (annual)

start of the 2007 crisis. The inverse of the Frisch elasticity of labor supply ψ is set equal to 2.2, following Galí and Monacelli (2016).

The remaining parameters are chosen using data from the euro area.[13] The euro area is an interesting case because, as discussed by Lane (2012) and Shambaugh (2012), it is a large currency union that developed significant imbalances across its members in the run-up to the global financial crisis, while these imbalances were reversed during the post-crisis years. For simplicity, I will interpret the entire model economy as representing the euro area, and, for most of the paper, I will abstract altogether from financial transactions between the euro area and the rest of the world. The calibration strategy thus consists in choosing values for the parameters so that the steady state of the model matches some key aspects of euro area countries. Online Appendix E provides details on the construction of the series used in the calibration.

The share of tradable goods in consumption and the labor share in both sectors are chosen to match the corresponding statistics for the euro area. Hence, the share of tradable goods in consumption is set to $\omega = 0.2$, while the labor share in production in both sectors is set to $\alpha_T = \alpha_N = 0.65$. These are in the range of the values commonly assumed in the literature.

To save on state variables I assume that productivity is the same in both sectors, so that $A_{i,t}^T = A_{i,t}^N = A_{i,t}$.[14] Productivity follows a log-normal AR(1) process $\log(A_{i,t}) = \rho \log(A_{i,t-1}) + \varepsilon_{i,t}$. This process is approximated with the quadrature procedure of Tauchen and Hussey (1991) using 13 nodes.[15] The first order autocorrelation ρ and the standard deviation of the productivity process σ_A are set respectively to 0.92 and to 0.024, to reproduce the average across euro area countries of the corresponding moments of de-trended labor productivity.

---

13. In the calibration, the euro area is defined as the aggregate of Austria, Belgium, Finland, Germany, Greece, Ireland, Italy, Netherlands, Portugal and Spain.

14. In a previous version of the paper I experimented with a version of the model in which productivity shocks are present only in the tradable sector. None of the key results of the paper is affected by this alternative assumption.

15. I use the weighting function proposed by Flodén (2008), which delivers a better approximation to high-persistence AR(1) processes than the weighting function originally suggested by Tauchen and Hussey (1991).
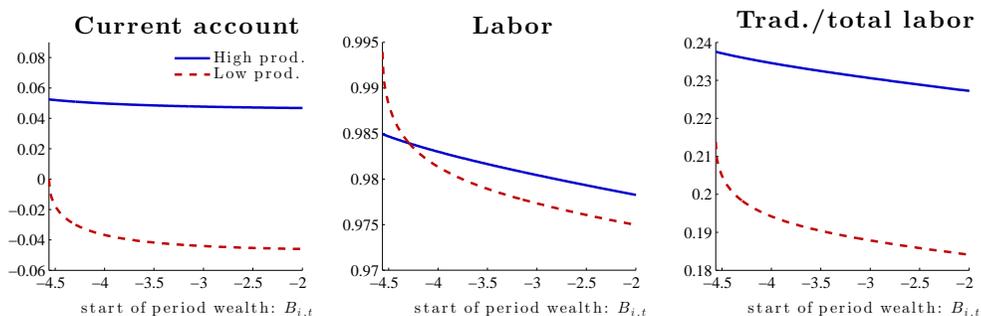
FIGURE 2. Policy functions in steady state. Notes: the high (low) productivity lines refer to economies hit by a productivity shock about two standard deviations above (below) the mean.

The existing literature offers little guidance on how to set κ, the borrowing limit in the initial steady state. One of the key variables determined by κ is the stock of gross world debt, that is the sum of the net foreign asset positions of debtor countries.[16] I set $\kappa = 4.56$ to match a world gross debt-to-annual GDP ratio of 21%.[17] This target corresponds to the sum of the net external liability positions of the euro area debtor countries in 2008, expressed as a fraction of the euro area annual GDP.[18] I choose 2008 as the benchmark year because later on I will use the sharp contraction in capital inflows experienced in 2009 by euro area debtor countries to parametrize the deleveraging shock. This value of κ implies that in the initial steady state a country can borrow up to 66% of its average GDP.

2.3. Steady state

Before proceeding with the analysis of the deleveraging episode, this section briefly describes the steady state policy functions and the stationary distribution of the net foreign asset-to-GDP ratio.

---

16. Given that bonds are in zero net supply at the world level, the stock of gross world debt also corresponds to the sum of the net foreign asset positions of creditor countries.

17. Throughout the paper, consistent with national accounts, I define GDP as the value of production at constant prices
$$GDP_{i,t} = Y_{i,t}^T + p^N Y_{i,t}^N,$$
where p^N is the unconditional mean of the relative price of non-tradable goods in the initial steady state, which is equal for every country. Naturally, world GDP is defined as $\int_0^1 GDP_{i,t} di$.

18. Spain is, by far, the country that had the highest net foreign liability-to-euro area GDP ratio in 2008, equal to 9%. Other countries that in 2008 had sizable net foreign liability positions expressed as a fraction of euro area GDP are France, Greece, Ireland, Italy and Portugal. Austria and Finland both had a negative net foreign asset position in 2008, but their external liabilities were very small compared to euro area GDP. Taking 2007 as the base year would give a very similar target, precisely a world gross debt-to-GDP ratio of 21.4%. Data are from Lane and Milesi-Ferretti (2007).

Figure 2 displays the optimal choices for the current account, total labor and the fraction of labor allocated to the tradable sector as a function of $B_{i,t}$, the stock of wealth at the start of the period, for an economy hit by a good productivity shock, solid lines, and by a bad productivity shock, dashed lines. The left panel shows the current account. As it is standard in models in which the current account is used to smooth consumption over time, a country runs a current account surplus and accumulates foreign assets when productivity is high, while it runs a current account deficit and reduces its stock of foreign assets when productivity is low.[19] Intuitively, fluctuations in productivity generate fluctuations in wages and profits, and so in households' income. For instance, when productivity is low income is also low, and households borrow to mitigate the impact of the temporarily low income on consumption, giving rise to a current account deficit. Conversely, when productivity is high income is high, and households save generating a current account surplus. The borrowing limit, however, interferes with consumption smoothing because it restricts the amount of new debt that an already indebted household can take in response to a negative income shock. This feature of the economy explains why the deficit in the current account associated with a low realization of the productivity shock decreases as the start-of-period wealth falls. For instance, when $B_{i,t} = -\kappa$, households cannot increase their debt further and the change in net foreign assets following a low realization of the productivity shock is equal to zero.

The middle panel illustrates the optimal choice of labor. In general, equilibrium labor is higher when productivity is high, because when productivity is higher firms are able to pay higher wages and this induces households to supply more labor. But this pattern is reversed for low levels of wealth. This is due to the fact that highly indebted households cannot rely extensively on borrowing to smooth the impact of negative income shocks on consumption. Hence, at low levels of wealth, households mitigate the impact of negative productivity shocks on consumption by increasing their labor supply. As illustrated by the right panel, the share of labor allocated to the tradable sector follows a similar pattern. In particular, as the start of period wealth falls more labor is allocated to the tradable sector. Intuitively, credit frictions impact disproportionally production in the tradable sector, because they interfere with tradable consumption smoothing.

Figure 3 shows the steady state distribution of the net foreign asset-to-annual GDP ratio. The distribution is truncated and skewed toward the left. Both of these features are due to the borrowing limit. In fact, while there is no limit to the positive stock of

---

19. This effect generates a positive steady state correlation between the current account and GDP, while in the data the current account is typically countercyclical. There are several approaches that could correct this counterfactual implication of the model. One possibility would be to introduce endogenous capital accumulation. Modeling capital accumulation would make the framework more realistic, but at the cost of making it much more complicated to solve, and I leave this relevant extension for future work. Another possibility would be to introduce shocks to the supply of savings, for example in the form of shocks to the discount factor β. I explored this possibility and the introduction of saving shocks does not affect significantly the behavior of the economy during deleveraging. I chose to focus on productivity shocks because they are easier to quantify.
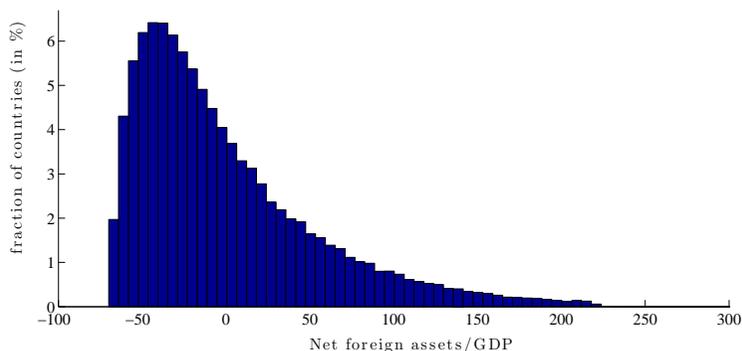
FIGURE 3. Steady state distribution of net foreign assets/GDP.

net foreign assets that a country can accumulate, the borrowing constraint imposes a bound on the negative net foreign asset position that a country can reach. In particular, the largest net foreign liability position-to-GDP ratio that a country can reach in the initial steady state is close to 70%.[20]

3. Adjustment to a deleveraging shock

This section analyzes the response of the economy to a deleveraging shock, defined as a large tightening of the borrowing limit.[21] I consider a world economy that starts from the steady state described in Section 2.3 and that, from period 0 on, transitions toward a new steady state characterized by a tighter borrowing limit $\bar{\kappa}$, where $\bar{\kappa} < \kappa$. The adjustment of the borrowing limit is gradual and follows the log-linear path

$$\log(\kappa_t) = \rho_\kappa \log(\kappa_{t-1}) + (1 - \rho_\kappa) \log(\bar{\kappa}),$$

for $t \geq 0$.[22] The initial fall in the borrowing limit happening in $t = 0$ is not anticipated by agents, while from period 0 on agents correctly anticipate the path of κ_t.

---

20. This is in line with the net foreign liability-to-GDP ratios in Ireland, Greece and Spain in 2008, which were respectively 68%, 73% and 75%. Instead, in 2008 Portugal had a significantly higher ratio of net foreign liability-to-GDP, equal to 95%. Data are from Lane and Milesi-Ferretti (2007).

21. The model is silent about the causes behind the drop in the borrowing limit. For example, access to credit could be restricted because of a banking crisis. Or alternatively, a drop in house prices, perhaps due to the bursting of a bubble as in Martin and Ventura (2012), could reduce the value of collateral in the hands of households and lead to a reduction in their ability to borrow.

22. One reason to consider a gradual adjustment of the borrowing limit is the fact that the model features only debt contracts that last one period, that is one quarter. In reality, debt can take maturities that are longer than one quarter. Considering a gradual adjustment in the borrowing limit is a simple way of capturing the fact that long term debt allows agents to adjust gradually to the new, tighter, credit conditions.

Choosing values for the parameters $\bar{\kappa}$ and ρ_{κ} is a difficult task. Hence, I start to present the results for a benchmark parameterization, and later on provide some robustness analysis. I set the benchmark values of $\bar{\kappa}$ and ρ_{κ} to match the abrupt improvement in the current account experienced by Ireland, Greece, Portugal and Spain, the so-called GIPS countries, in the aftermath of the 2008 global financial crisis. I set the final borrowing limit to $\bar{\kappa} = 3.2$, so that the fraction of countries constrained by the new borrowing limit, that is those countries for which $B_{i,0} < -\bar{\kappa}$, accounts for 18.5% of world GDP in the initial steady state. This is in line with the fraction of euro area GDP accounted by GIPS countries in 2008, which is 18.4%. To set ρ_{κ}, the parameter which determines the speed of adjustment of the borrowing limit, I employ the following strategy. In 2009 the GIPS countries experienced an improvement in their current accounts collectively equal to 1 percent of 2008 euro area GDP.[23] Accordingly, I set $\rho_{\kappa} = 0.7$ so that after four quarters the tightening of the borrowing limit generates an amount of forced savings from high-debt countries equal to 1% of initial-steady-state world GDP.[24]

3.1. Aggregate dynamics

Figure 4 displays the transitional dynamics of the world economy following the deleveraging shock. The figure shows the path for the exogenous borrowing limit, and the responses of the world gross debt-to-GDP ratio, the world interest rate and world GDP.

The tightening of the borrowing limit triggers a decrease in the foreign debt position of highly indebted countries. At the same time, surplus countries are forced to reduce their positive net foreign asset position, which is the counterpart of foreign debt in indebted countries. The result is a progressive compression of the net foreign asset distribution. As showed by the the top-right panel of Figure 4, the world debt-to-GDP ratio gradually falls toward its value in the final steady state, which is equal to 14.7%.

---

23. Indeed, the sum of the current account deficits of GIPS countries expressed as a fraction of 2008 euro area GDP passed from 2.8% in 2008 to 1.8% in 2009. To compute these statistics I used data provided by Lane and Milesi-Ferretti (2007).

24. Formally, define forced savings between period 0 and period $t \geq 0$ as the reduction in world debt needed to satisfy the period t borrowing limit $\int_{-\bar{\kappa}}^{-\kappa_t} (-\kappa_t - B_i) \Psi(B) \, di$, where the absence of time subscript denotes variables referring to the initial steady state. I set $\rho_{\kappa} = 0.7$ so that

$$\frac{\int_{-\bar{\kappa}}^{-\kappa_4} (-\kappa_4 - B_i) \Psi(B) \, di}{4GDP} = 0.01,$$

where steady state GDP is multiplied by 4 to convert it to its annual value. In words, the above expression means that the group of countries that have a debt position in the initial steady state higher than the period 4 borrowing limit is forced by the deleveraging shock to reduce debt by an amount equal to 1% of initial-steady-state world GDP.
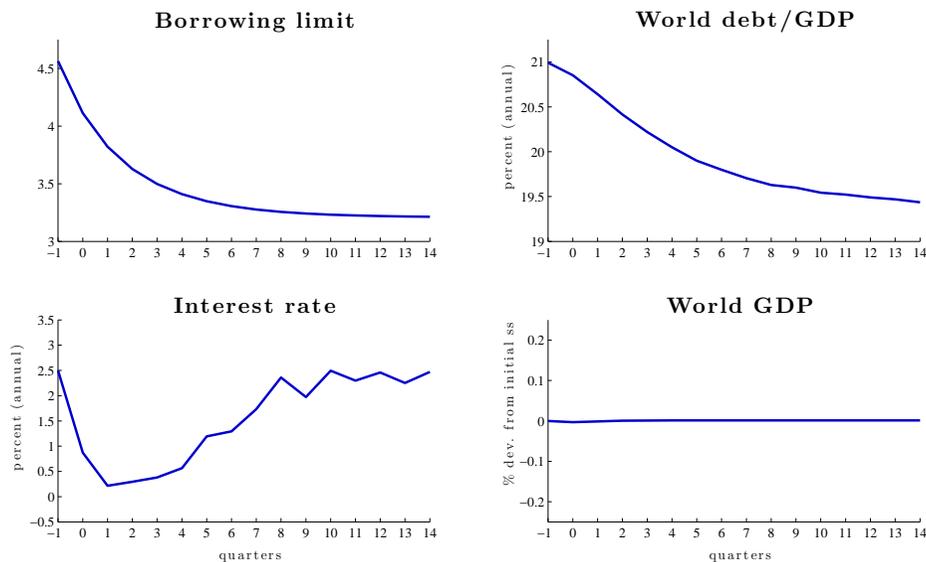
FIGURE 4. Response to deleveraging shock. Notes: world debt refers to world gross debt, defined as $\int_{-\kappa_t}^{0} B_{i,t+1}/R_t \, di$. World GDP is defined as $\int_{0}^{1} Y_{i,t}^{T} + p^{N} Y_{i,t}^{N} di$, where p^{N} denotes the unconditional mean of $p_{i,t}^{N}$ in the initial steady state.

The world interest rate drops sharply in response to the deleveraging shock and overshoots its value in the new steady state.[25] The fall in the interest rate signals an increase in the desire to save, or equivalently a fall in the desire to consume. This is due to two distinct effects. First, countries that start with a high level of foreign debt, more precisely countries that start with a stock of bonds $B_{i,0} < -\bar{\kappa}$, are forced to reduce their foreign debt position. This forced reduction in debt corresponds to a forced increase in savings that depresses the demand for consumption in high-debt countries. Second, even the countries that are sufficiently wealthy so that they are not directly affected by the tightening of the borrowing limit, the unconstrained countries, experience an increase in the propensity to save. In fact, unconstrained countries want to accumulate precautionary savings to self-insure against the risk of hitting the now-tighter borrowing limit in the future. These two effects point toward an increase in the propensity to save at the world level. In order to restore equilibrium on the bonds market the world interest rate has to fall, so as to induce the unconstrained countries to absorb the forced savings coming from high-debt, borrowing-constrained economies.

To illustrate these effects, I perform the following experiment. I consider a case in which the model economy, rather than being financially closed with respect to the rest of the world, is embedded in a larger global economy characterized by an exogenous global interest rate. To facilitate comparison with the benchmark case, the

---

25. The interest rate in the final steady state is lower compared to its value in the initial steady state, but quantitatively the difference is minuscule.
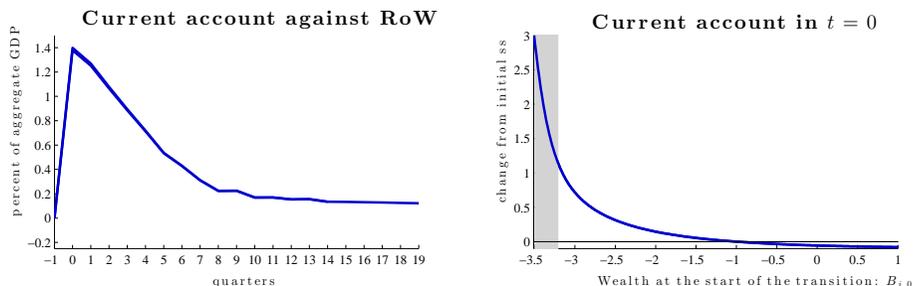
FIGURE 5. Current account response with fixed global interest rate. Notes: the transitional dynamics are computed assuming that $R_t = \bar{R}$ for $t \geq 0$, where $\bar{R}$ is the value of the world interest rate in the final steady state. The current account with respect to the rest of the world is defined as $\int_0^1 CA_{i,t} di$

global interest rate is set equal to the value taken by the interest rate in the final steady state of the benchmark economy. Moreover, again to ease comparison with the benchmark economy, I assume that the model economy has a zero net foreign asset position with respect to the rest of the world at the time when it is hit by the deleveraging shock. The left panel of Figure 5 shows that following the deleveraging shock the economy experiences several periods of large current account surpluses against the rest of the world. Intuitively, the deleveraging shock generates a rise in the economy's propensity to save. Since the interest rate is fixed, equilibrium savings rise, leading the economy to accumulate foreign assets against the rest of the world. One interesting question is how the rise in savings is distributed across different countries. To answer this question, the right panel of Figure 5 shows the period 0 response of the current account to the deleveraging shock across the initial distribution of net foreign assets.[26] The shaded area denotes the countries that start the transition with $B_{i,0} < -\bar{\kappa}$, and hence are forced to reduce their foreign debt by the tightening of the borrowing constraint. Naturally, these countries increase their current account surplus to deleverage. The key point, however, is that also those countries with $B_0 > -\bar{\kappa}$, but with an amount of initial foreign debt sufficiently close to the borrowing limit, experience an improvement in their current account. This is the result of the increase in the desire to save for precautionary reasons triggered by the deleveraging shock. The rise in precautionary savings in response to the deleveraging shock is a distinctive feature of this framework, and is absent in more stylized two-country models such as the one studied by Benigno and Romei (2014).[27]

---

26. To construct this figure, I first computed the response in period 0 to the deleveraging shock, assuming that the interest rate jumps immediately to its value in the final steady state, for every possible realization of the state variables $\{A_0, B_0\}$. Then I computed an aggregate response as a function of B_0 by taking the weighted average of the single country responses. The weights are given by the fraction of countries having a given realization of A_0 conditional on B_0.

27. In this respect, the model is close to Guerrieri and Lorenzoni (2017), who study the response of precautionary savings to a deleveraging shock in a closed economy.

Going back to the benchmark economy, the bottom-right panel of Figure 4 shows that the deleveraging shock leaves world GDP essentially unchanged. However, the lack of aggregate movements in world output masks important country-level composition effects, to which we turn next.

3.2. Response across the net foreign asset distribution

Figure 6 illustrates how the response to the deleveraging shock varies across the initial distribution of net foreign assets. The figure shows the response of the current account-to-GDP ratio, GDP, consumption, real wage and the share of output and consumption accounted by the tradable sector for three countries. The three countries are at the 10th, 20th and 75th percentile of the initial net foreign asset distribution. In order to highlight the heterogeneity due to the initial net foreign asset position, for the three countries productivity is held constant to its mean value.

The country at the 10th percentile captures the typical behavior of a high-debt financially-constrained economy. As shown by the top-left panel, the tightening of the borrowing limit generates a sudden stop in capital inflows, giving rise to several periods of sustained current account surpluses. To understand the macroeconomic implications, it is useful to go back to the equation describing the current account

$$CA_{i,t} = Y_{i,t}^T - C_{i,t}^T + B_{i,t} \left(1 - \frac{1}{R_{t-1}} \right).$$

This expression makes clear that a country can improve its current account by increasing its output of the tradable good, by decreasing the consumption of the tradable good or through a combination of both. Figure 6 shows that the high-debt country adjusts both through the output and the consumption margins. In fact, both output and the share of output accounted by tradables rise, while the opposite occurs for consumption. Hence, in high-debt countries the sudden stop in capital inflows leads to an economic expansion, and to a shift of productive resources from the non-tradable to the tradable sector.

The countries at the 20th and 75th percentile are sufficiently wealthy so that they are not directly affected by the constraint, and their adjustment follows an opposite pattern compared to high-debt economies. Indeed, the decrease in the world interest rate induces unconstrained countries to reduce their stock of foreign assets by running current account deficits. This is achieved trough a combination of lower production and higher consumption of tradable goods.

Hence, following a deleveraging shock the baseline model displays a shift of production of tradable goods from wealthy unconstrained countries toward high-debt constrained ones. This change in the pattern of production plays a key role in the adjustment, because it redistributes income from countries which have a low propensity to consume, the unconstrained countries, toward countries that have a high propensity to consume, the borrowing constrained countries. In fact, the asymmetry in the response of production of tradable goods between borrowing constrained and
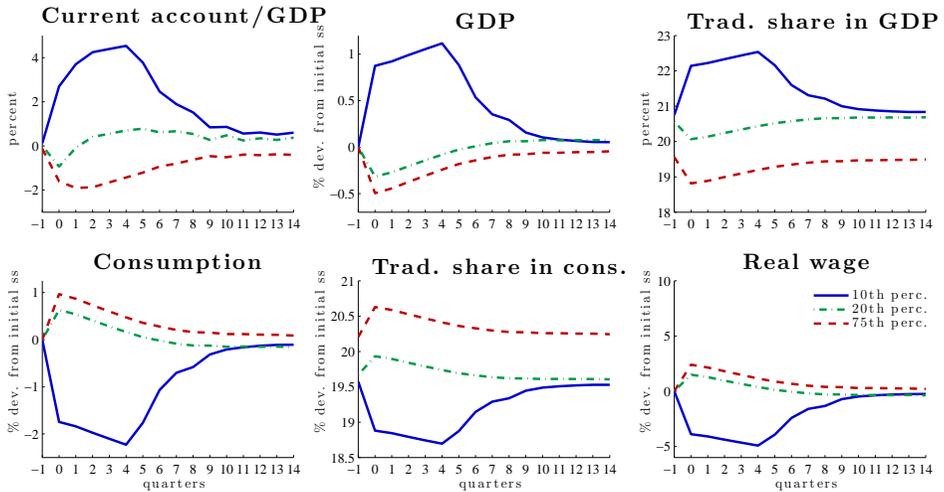
FIGURE 6. Response to deleveraging shock across the NFA distribution. Notes: GDP and consumption are the value of production and consumption at constant prices. Non-tradable goods are weighted using the unconditional mean of p^N in the initial steady state. The real wage is the wage in units of tradable goods.

unconstrained countries mitigates the rise in the world propensity to save caused by the deleveraging shock, thus limiting the fall in the world interest rate.[28]

The real wage is the key price that has to adjust to allow production to respond to the deleveraging shock. This can be seen by rearranging the optimality condition for firms in the tradable sector to obtain

$$L_{i,t}^T = \left(\frac{\alpha_T A_{i,t}}{w_{i,t}} \right)^{\frac{1}{1-\alpha_T}}.$$

This expression implies that, given $A_{i,t}$, an increase in employment in the tradable sector in country i has to come with a decrease in the real wage $w_{i,t}$. In fact, as shown by the bottom-right panel of Figure 6, in the baseline economy the adjustment to the deleveraging shock entails a decrease in real wages in high-debt constrained economies and an increase in real wages in the rest of the world.

The adjustment in the real wage is due to two different effects. First, following the deleveraging shock households in high-debt countries increase their labor supply to boost labor income and to repay debts without cutting consumption too severely. Conversely, households in unconstrained countries contract their labor supply in response to the fall in the interest rate and the subsequent rise in consumption. Second,

---

28. In Online Appendix C I study a simplified version of the model which allows for an analytic solution. This exercise provides further insights on the interaction between the endogenous response of production to the deleveraging shock and the behavior of the world interest rate.

the fall in consumption in high-debt countries corresponds to a negative demand shock for the non-tradable sector, which leads to a fall in labor demand from firms producing non-tradable goods. The opposite occurs in wealthy unconstrained countries. Both of these effects point toward a fall in real wages in high-debt constrained economies, and a rise in the rest of the world.

The empirical evidence reviewed in the introduction suggests that nominal wages adjust sluggishly to shocks. In particular, a recurrent pattern in severe recessions is that nominal wages do not fall much, even in the face of large rises in unemployment. It is then difficult to imagine that the adjustment in real wages required by the deleveraging shock could come from an adjustment in nominal wages. But what are the macroeconomic implications of this friction? To answer this question we need to introduce a model with nominal wage rigidities.

4. A model with nominal rigidities

This section studies the adjustment to a deleveraging shock in presence of nominal wage rigidities. In the interest of space, here I provide an informal description of the model, while the details can be found in Online Appendix D.

The basic structure of the model is the same as the one of the baseline model of Section 2. There are two main differences. First, there is monopolistic competition on the labor market. In fact, as in Erceg et al. (2000), households supply differentiated labor services, which enter firms' production function with the elasticity of substitution ε. Second, nominal wages are negotiated by labor unions, which act in the interest of households. Specifically, each labor union sets the wage of a single type of labor service. Once wages are set, households stand ready to supply the quantity of labor demanded by firms. In spite of these differences, in absence of frictions in the wage-setting process the model is isomorphic to the baseline one.

I introduce frictions in the adjustment of nominal wages by assuming that labor unions update their information about the state of the economy infrequently. This implies that unions might set nominal wages based on outdated information, and so nominal wages might not respond immediately to unexpected shocks or changes in monetary policy. This friction creates a channel through which monetary policy can affect the real economy.

To implement this idea, I adopt a variant of the Mankiw and Reis (2002) model of imperfect information, in which in every period agents have a constant probability of updating their information set. More precisely, I assume that every period only a fraction $0 < \varphi < 1$ of the unions observes the state variables describing the global economy, that is the cross-country distribution of net foreign assets and the path of the borrowing limit κ_t. Instead, wage setters update continuously their information about the country-level state variables, that is the stock of foreign assets held by the country at the start of the period and the realization of the productivity shock. This setting captures an environment in which wage setters pay more attention to the idiosyncratic shocks that hit their country frequently, rather than to the rare shocks

hitting the global economy. More broadly, this asymmetric information structure is meant to capture an environment in which there is enough wage flexibility to deal with normal business cycle fluctuations driven by the productivity shocks. Instead, wages fail to adjust immediately to large and rare shocks, such as the one-time previously unexpected drop in the borrowing limit considered in our deleveraging experiment.[29]

It turns out that, given that the only aggregate shock considered is a one-time fully unanticipated shock to the borrowing limit κ_t, the equilibrium behavior of wage setters takes a very simple form. In fact, both in the initial and final steady states wage setters have perfect information about the state of the economy. Hence, in steady state the allocations correspond to the one of the baseline model with flexible wages discussed in Section 2. Instead, during the transition from the initial to the final steady state, in every period t a fraction $(1 - \varphi)^t$ of wage setters has not yet received information about the global deleveraging shock. Uninformed unions act on the basis of outdated information, and set nominal wages according to the pricing rule of the initial steady state. More formally, during the transition the aggregate nominal wage $W_{i,t}$ follows the path

$$W_{i,t} = \left(\left(1 - (1 - \varphi)^t\right) \left(W_{i,t}^{in}\right)^{1-\varepsilon} + (1 - \varphi)^t \left(W_{i,t}^{un}\right)^{1-\varepsilon} \right)^{\frac{1}{1-\varepsilon}},$$

where $W_{i,t}^{in}$ and $W_{i,t}^{un}$ denote respectively the nominal wage set by informed and uninformed unions. This equation implies that nominal wages adjust sluggishly to the deleveraging shock in the short run, but the economy approaches the full information benchmark as $t \to \infty$.

Because of the sluggish adjustment of nominal wages, monetary policy can affect the transitional dynamics triggered by the deleveraging shock. I consider two different monetary policy regimes. The main focus of the analysis is on a world in which every country belongs to a single monetary union. Under this regime every country $i \in [0, 1]$ shares the same currency, and there is a single central bank setting monetary policy. Consistent with the inflation objective of the European Central Bank, I focus attention on a central bank that targets the average CPI inflation across the member countries. More precisely, defining $\pi_{i,t}$ as CPI inflation, the objective of the central bank of the monetary union is to set $\int_0^1 \pi_{i,t} di = \bar{\pi}$. As a comparison, in this section I also consider a flexible exchange rate regime, in which every country has its own currency and runs monetary policy independently. To allow for a clean comparison with the monetary union, in every country i the central bank objective is to set $\pi_{i,t} = \bar{\pi}$. I will start by assuming that central banks always attain their inflation targets. Later on, in Section

---

29. To be clear, the assumption of an asymmetric information structure is not made on the ground that wage rigidities are unimportant to explain normal business cycle fluctuations driven by domestic productivity shocks. Rather, the objective is to focus attention on the interactions between wage rigidities and the transitional dynamics triggered by a large global deleveraging shock, abstracting from the, already well-understood, role of wage rigidities in shaping the response of the economy to standard productivity shocks. That said, it would be interesting to explore an environment in which wage setters have imperfect information about domestic, as well as global, shocks.
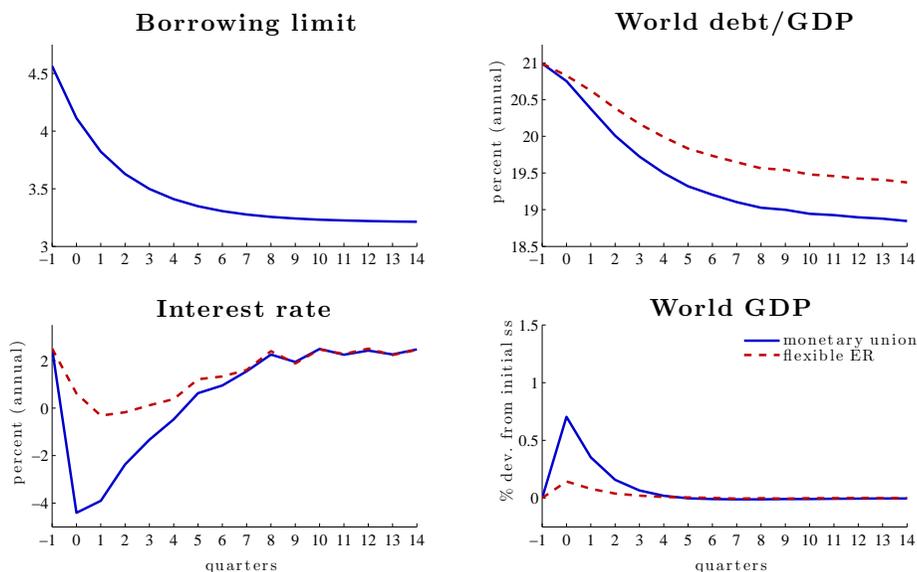
FIGURE 7. Response to deleveraging shock with nominal rigidities. Notes: world debt refers to world gross debt, defined as $\int_{-\kappa_t}^{0} B_{i,t+1}/R_t \, di$. World GDP is defined as $\int_{0}^{1} Y_{i,t}^T + p^N Y_{i,t}^N di$, where p^N denotes the unconditional mean of $p_{i,t}^N$ in the initial steady state.

5, I consider a case in which the central bank might fail to reach its inflation objective because of the zero lower bound on the nominal interest rate.

For the model with nominal rigidities there are two additional parameters to be set, ε and φ. The elasticity of substitution across different labor types is set to $\varepsilon = 4.3$, following Galí and Monacelli (2016). In the benchmark calibration I set φ, the probability that a wage setter updates its information set, to .2. This is in line with the average duration of wages usually assumed in models featuring a Calvo friction (Erceg et al., 2000; Galí and Monacelli, 2016). I later perform a robustness analysis along different assumptions on the value of φ.

Figure 7 presents the response of aggregate variables to the deleveraging shock. The solid lines refer to the monetary union, while the dashed lines refer to the world with flexible exchange rates. The first result is that the behavior of the flexible exchange rate economy is strikingly similar to the one of the flexible-wage economy studied in Section 2. Hence, as long as exchange rates are flexible and monetary policy stabilizes CPI inflation, frictions in the adjustment of nominal wages do not affect aggregate dynamics in any significant way.

The monetary union, instead, experiences a particularly large drop in the world interest rate. In fact, under a monetary union the fall in the interest rate is about three times larger than under flexible exchange rates. Hence, the combination of nominal wage rigidities and fixed exchange rates amplifies the fall in the interest rate following a deleveraging shock.
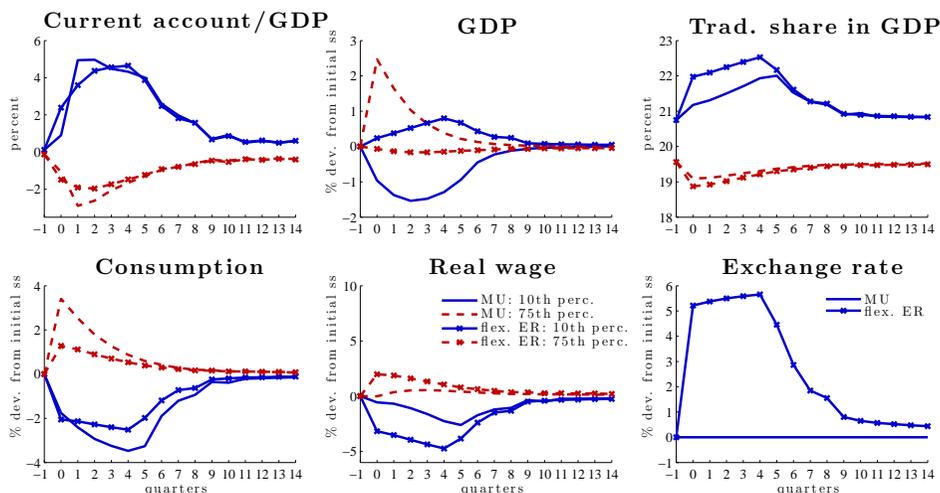
FIGURE 8. Response to deleveraging shock across the NFA distribution with nominal rigidities. Notes: GDP and consumption are the value of production and consumption at constant prices. Non-tradable goods are weighted using the unconditional mean of p^N in the initial steady state. The real wage is the wage in units of tradable goods. The exchange rate is defined as the units of the 10th percentile country's currency needed to buy one unit of the currency of the 75th percentile country.

To gain intuition about this result, it is useful to look at the country-level responses, shown by Figure 8. The solid lines refer to a high-debt economy at the 10th percentile of the initial net foreign asset distribution, while the dashed lines are for a wealthy country at the 75th percentile.[30] Moreover, the unmarked lines refer to the monetary union, while cross marks indicate the world with flexible exchange rates. Under both regimes, the high-debt country is forced to improve its current account by the tightening of the borrowing constraint. As in the flexible wage economy, under flexible exchange rates the high-debt country improves its current account by increasing the production of tradable goods, while the wealthy country contracts its production of tradables. Instead, in the monetary union this channel of adjustment is essentially shut off. In fact, in the monetary union the high-debt country experiences an economic contraction, and the shift of productive resources from the non-tradable to the tradable sector is much smaller than under flexible exchange rates. Similarly, in the monetary union tradable production in the wealthy unconstrained country does not fall as much as under flexible exchange rates.

The muted response of tradable production to the deleveraging shock can be traced to the fact that in the monetary union real wages fail to adjust, as shown by the bottom-middle panel of Figure 8. To understand how the exchange rate regime affects the behavior of real wages, consider that the real wage is defined as $W_{i,t}/P_{i,t}^T$, where $P_{i,t}^T$ is the price of the tradable good in terms of country i's currency. Now imagine a

---

30. For both economies, productivity is kept constant and equal to its mean value.

case in which the nominal wage is fully sticky, so that $W_{i,t}$ does not respond to the deleveraging shock. In this case, the adjustment has to come through movements in $P_{i,t}^T$. In particular, to mimic the adjustment under flexible wages, $P_{i,t}^T$ must rise in high-debt economies and fall in wealthy unconstrained countries. Now consider that the absence of trade frictions implies that the law of one price holds for the tradable good, so that

$$P_{i,t}^T = S_{i,t}^j P_{j,t}^T \quad \text{for any} \quad i, j \in [0, 1].$$

In this expression, $S_{i,t}^j$ is the exchange rate between country i and country j, defined as the units of country i's currency needed to purchase one unit of country j's currency. This equation implies that, to replicate the adjustment under flexible wages, the currencies of high-debt countries need to depreciate against those of wealthy countries. This is precisely what happens under flexible exchange rates, as shown by the bottom-right panel of Figure 7.[31] Instead, in a currency union by definition $S_{i,t}^j = 1$ for any i and j, so that the asymmetric adjustment in $P_{i,t}^T$ across financially constrained and unconstrained countries cannot occur. Hence, the combination of nominal wage rigidities and fixed exchange rates shuts down the response of real wages and of the output of tradable goods to the deleveraging shock. In reality, wages are only partially rigid, and some wage adjustment occurs also in the monetary union. However, quantitatively the adjustment in wages is small, which explains why the exchange rate regime affects the economy's response to the deleveraging shock.[32]

The outcome of this lack of adjustment is that in the monetary union the improvement in the current account in high-debt countries comes mainly from a large drop in consumption, as displayed by the bottom-left panel of Figure 8. The fact that constrained countries have to adjust mainly through the consumption margin implies that, following the deleveraging shock, world demand for consumption falls more in the monetary union than under flexible exchange rates. In turn, the interest rate has to fall by more to induce unconstrained countries to increase consumption and pick up the slack left by borrowing constrained economies. Hence, the lack of exchange rate flexibility places the burden of adjustment on the interest rate. As we will see,

---

31. To understand why under flexible exchange rates $P_{i,t}^T$ rises in high-debt countries, consider that, as explained in Online Appendix D, the CPI is

$$\left(\frac{P_{i,t}^T}{\omega} \right)^{\omega} \left(\frac{P_{i,t}^N}{1 - \omega} \right)^{1-\omega}.$$

In high-debt countries the deleveraging shock generates a fall in the demand for non-traded goods, and hence a fall in $P_{i,t}^N$. It follows that, in order to insulate the CPI from the shock, $P_{i,t}^T$ has to rise. The opposite occurs in wealthy unconstrained countries.

32. More precisely, some wage adjustment occurs in high debt countries, which experience a mild fall in nominal wages. Instead, the rise in nominal wages in the rest of the union is quantitatively negligible. This explains why, as showed by the bottom-right panel of Figure 7, the aggregate output of the monetary union rises mildly in response to the deleveraging shock. As we will see in Section 5, once the zero lower bound is taken into account, deleveraging generates an aggregate recession in the monetary union.

this has important implications for the macroeconomic adjustment to deleveraging in a monetary union if interest rates are close to the zero lower bound.

Before turning to the zero lower bound, however, it is useful to understand why in a monetary union deleveraging generates a recession in high-debt countries. Taken together, the top-center and top-right panels of Figure 8 indicate that the recession in high-debt countries is driven by a fall in the production of non-traded goods.[33] To understand why this is the case, it is useful to recast the equilibrium on the market for non-tradables as the intersection of an aggregate demand and an aggregate supply schedule. The aggregate demand (AD) schedule can be obtained by rewriting equation (4) as

$$ C_{i,t}^N = \frac{1-\omega}{\omega} \frac{P_{i,t}^T}{P_{i,t}^N} C_{i,t}^T, \tag{AD} $$

where $P_{i,t}^N$ denotes the price of the non-tradable good in terms of the domestic currency. Instead, the aggregate supply schedule can be obtained by rewriting the labor demand by firms in the non-tradable sector as

$$ Y_{i,t}^N = A_{i,t}^{\frac{1}{1-\alpha_N}} \left(\alpha_N \frac{P_{i,t}^N}{W_{i,t}} \right)^{\frac{\alpha_N}{1-\alpha_N}}, \tag{AS} $$

where I have used $Y_{i,t}^N = A_{i,t} \left(L_{i,t}^N\right)^{\alpha_N}$. In a monetary union, since tradable production does not react, the deleveraging shock generates a sharp fall in tradable consumption in high-debt countries. The AD equation shows that the fall in tradable consumption corresponds to a negative demand shock for non-tradable goods. This effect points toward lower production of non-traded goods. The fall in tradable consumption, however, also generates a rise in labor supply, and, with flexible wages, a fall in $W_{i,t}$. According to the AS equation, a lower $W_{i,t}$ reduces $P_{i,t}^N$, because the fall in labor costs leads firms to cut prices. This effect mitigates the drop in non-tradable production. With sticky wages, instead, $W_{i,t}$ cannot adjust. Still, if exchange rates are flexible, high-debt countries experience a rise in $P_{i,t}^T$ because of the exchange rate depreciation. From the AD equation, this induces an expenditure switching effect that sustains demand for non-tradables and mitigates the fall in $Y_{i,t}^N$. In a monetary union with wage rigidities both channels of adjustment are absent, which explains why high-debt countries experience a drop in GDP concentrated in the non-tradable sector.

Summarizing, the interaction between nominal wage rigidities and fixed exchange rates gives rise to a large drop in the world interest rate following the deleveraging shock, and a recession in the countries that end up being financially constrained. The next section shows how the recession can spread to unconstrained countries if the deleveraging shock pushes the union into a liquidity trap.

---

33. This is consistent with the empirical evidence provided by Benigno et al. (2015), who show that in the data contractions in capital inflows are typically accompanied by drops in the production of non-tradable goods.

5. Deleveraging and liquidity trap in a monetary union

As we have seen, deleveraging in a monetary union entails a sharp drop in the real interest rate. This result suggests that, if expected inflation is low enough, deleveraging can push the nominal interest rate of the currency union all the way to its zero lower bound. At that point, the central bank is not able to stimulate the economy enough to hit its inflation target, and a liquidity trap occurs. The objective of this section is to understand under which conditions deleveraging across members of a monetary union gives rise to a liquidity trap, as well as the impact that the liquidity trap has on output and welfare.

To understand whether the deleveraging shock generates a liquidity trap, we have to take a stance on the central bank's inflation target, which determines agents' inflation expectations. In line with the price stability objective of the European Central Bank, I set the benchmark inflation target to 2% on a yearly basis, so that $\bar{\pi} = 1.02^{1/4}$. Now define $\hat{R}_t^n$ as the gross nominal interest rate consistent with the central bank's inflation target. In this section the focus is on a currency union in which the central bank sets the interest rate according to $R_t^n = \max\left(\hat{R}_t^n, 1\right)$. In words, the central bank implements the inflation target as long as this does not imply a negative nominal rate, otherwise it sets the nominal interest rate to zero.

5.1. Dynamics during liquidity trap

Figure 9 shows the response of the monetary union to the deleveraging shock. As shown by the top-right panel, the nominal interest rate hits the zero lower bound during the first two periods of deleveraging. The binding zero lower bound indicates that it is not possible for the central bank to attain its inflation target. In fact, at the target inflation rate the goods market does not clear, since demand for consumption is too weak to absorb producers' desired output. Excess supply induces firms to cut prices, as illustrated by the bottom-left panel. The unexpected fall in prices leads to a rise in real wages, since nominal wages do not perfectly adjust to the deleveraging shock. In turn, higher wages reduce the profitability of employing labor, leading to a fall in production. Indeed, this is the mechanism through which the goods market equilibrium is restored.

The result is that deleveraging gives rise to a prolonged recession, lasting about two years, that affects all the countries belonging to the monetary union. As shown by the bottom-middle panel of Figure 9, on impact world output falls by almost 2 percentage points below its value in the initial steady state. Interestingly, the drop in GDP is sufficiently large so that initially the world gross debt-to-GDP ratio increases. Only starting from the second quarter the ratio of world debt-to-GDP starts declining.[34] There is, moreover, substantial heterogeneity in the output response

---

[34]. This result is in line with the path of the private debt-to-GDP ratio observed during several deleveraging episodes. See McKinsey (2010, 2012).
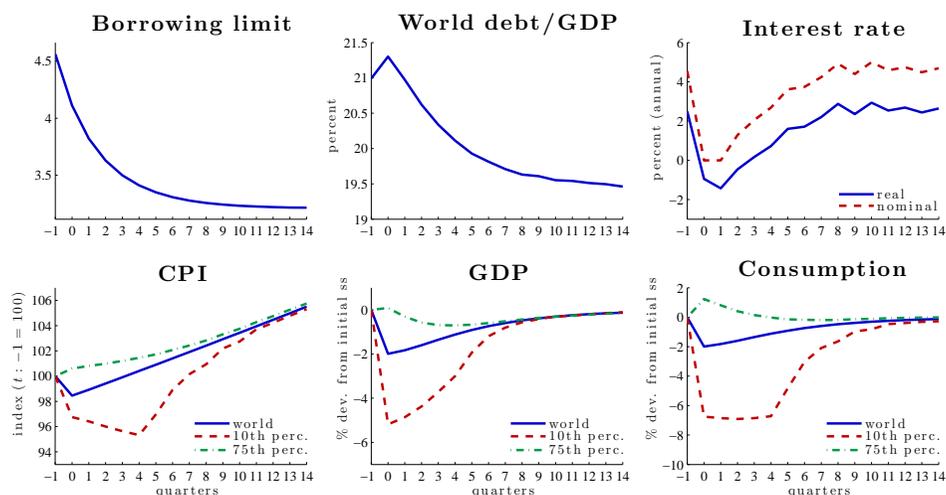
FIGURE 9. Response to deleveraging shock in a monetary union. Notes: world debt refers to world gross debt, defined as $\int_{-\kappa_t}^{0} B_{i,t+1}/R_t \, di$. World GDP and consumption are respectively defined as $\int_{0}^{1} Y_{i,t}^T + p^N Y_{i,t}^N di$ and $\int_{0}^{1} C_{i,t}^T + p^N C_{i,t}^N di$, where p^N denotes the unconditional mean of $p_{i,t}^N$ in the initial steady state. CPI is the average consumer price index.

across the members of the union. High-debt countries suffer a particularly severe recession. For instance, as shown in Figure 9, on impact GDP in the country at the 10th percentile of the initial net foreign asset distribution falls by almost 6%. Instead, wealthy countries experience a mild contraction, as it is the case for the country at the 75th percentile of the initial wealth distribution. The heterogeneous output response is due to the presence of non-traded goods. In fact, the fall in production of tradable goods is uniform across the monetary union, because production of the traded good depends on the demand from all the countries in the union. Instead, production of non-traded goods, which depends on local demand, falls more in high-debt countries, because these are the countries that experience the largest drop in consumption. In fact, as shown by the bottom-right panel of Figure 9, the heterogeneity in the consumption response is particularly large. While the 10th percentile country experiences a deep fall in consumption, consumption in the 75th percentile country rises slightly above its value in the initial steady state.

Table 2 provides further information on the impact on output of the deleveraging episode, by showing the cumulative output loss occurring in the two years after the deleveraging shock. The aggregate cumulative output loss amounts to a sizable 10% of GDP in the initial steady state. These aggregate output losses are mainly driven by the deep recession experienced by high-debt countries. For instance, the losses in the countries at the 5th and 10th percentile of the initial net foreign asset distribution are respectively equal to 49.6% and 25.1% of their GDP in the initial steady state. This is one order of magnitude larger than the losses experienced by unconstrained countries.

TABLE 2. Cumulative output loss (% of quarterly steady state GDP).

	World	5th perc.	10th perc.	25th perc.	50th perc.	75th perc.
Benchmark	10.1	49.6	25.1	5.4	4.3	4.0
$\rho = 0.65$	23.0	69.6	44.4	17.6	16.3	15.9
$\rho = 0.75$	1.9	34.9	11.8	-2.1	-3.1	-3.4
$\varphi = 0.1$	36.5	105.6	69.1	28.6	25.9	25.2
$\varphi = 0.3$	3.3	25.9	9.8	0.6	0.0	-0.1

Notes: The cumulative output loss is computed as $\sum_{t=0}^{T}(GDP_{i,t}/GDP_i - 1) \cdot 100$, where GDP_i denotes GDP in the initial steady state. The output loss is computed over the two years following the deleveraging shock, so $T = 8$. For the country-level loss, productivity is assumed to be constant and equal to its mean value.

As an example, countries at the 25th, 50th and 75th percentile have cumulative losses respectively equal to 5.4%, 4.3% and 4% of their initial GDP.

Table 2 also shows how the impact of deleveraging on output varies with two key parameters, ρ and φ. First, the output losses are greater when deleveraging is faster, i.e. the lower ρ.[35] For example, moving from the benchmark value of $\rho = 0.7$ to $\rho = 0.65$ more than doubles the output losses. Instead, when $\rho = 0.75$ the output loss associated with deleveraging is negligible. These results point toward the importance of the "surprise" aspect of the deleveraging shock in generating a large drop in output.[36]

Second, higher wage rigidities magnify the output losses due to deleveraging. For instance, when $\varphi = 0.1$, so that every quarter a wage setter has a 10% probability of receiving information about the deleveraging shock, the aggregate cumulative output loss is almost four times larger than under the benchmark parametrization. This is an interesting result, in light of the fact that in the standard New Keynesian model higher price or wage flexibility amplifies the drop in output associated with a liquidity trap (Werning, 2011). This can be explained with the presence of two opposing effects. In the New Keynesian model, higher wage flexibility increases the deflation associated with a liquidity trap. In turn, expectations of future deflation raise the real interest rate, which depresses output. This effect implies that more flexible wages are associated with a larger output drop. While here this effect is present, there is another effect that goes in the opposite direction. In fact, as discussed in Section 4, in a monetary union wage rigidities prevent the reallocation of production from wealthy to high-debt countries, deepening the drop in world demand for consumption generated by the

---

35. Instead, holding constant the short-run path of κ_t, the results are largely unaffected by changes in the borrowing limit in the final steady state $\bar{\kappa}$.

36. To further investigate this point, I performed an experiment in which κ_t follows the same path as in the benchmark parametrization, except that the drop in the borrowing limit is announced to agents two periods in advance. Under this scenario, the fall in the interest rate is not large enough to make the zero lower bound bind. Moreover, the impact of deleveraging on aggregate output is negligible, while high-debt countries experience a mild contraction. Taking stock, these experiments suggest that to have a large impact on output the deleveraging shock must be perceived by agents as a low probability event.

deleveraging shock. This second effect, which turns out to dominate in the simulations, implies that more flexible wages mitigate the output drop during the liquidity trap.

5.2. Comparison with euro area crisis

Before moving on, it is useful to briefly compare the behavior of the model with the euro area experience in the aftermath of the 2008 global financial crisis. The dashed lines in Figure 10 show the path of euro area detrended GDP per capita, nominal interest rate, CPI inflation and real wage growth between 2007 and 2014. The figure also plots the response of the model to a deleveraging shock, calibrated as explained above, hitting the economy in 2008Q4. The solid lines refer to the model behavior under the benchmark parametrization ($\varphi = .2$), while the dash-dotted lines correspond to an alternative parametrization with more rigid wages ($\varphi = .1$).

Qualitatively, the model reproduces fairly well the behavior of output, CPI inflation and real wage growth during the first two years following the financial crisis. More specifically, the model captures the drops in output, price inflation and nominal rate, as well as the rise in real wages.[37] Both in the model and in the data, moreover, after the initial drop price inflation quickly returns close to the central bank target. Quantitatively, under the benchmark parametrization the model underestimates the output drop and the rise in real wages. This can be explained with the fact that the euro area was hit by other shocks, such as the collapse in global demand due to the global financial crisis, over the same period. Another possibility is that the benchmark parametrization might underestimate the wage rigidities characterizing the euro area in the aftermath of the financial crisis. In fact, increasing the degree of wage rigidities to $\varphi = 0.1$ brings the model significantly closer to the data in terms of output dynamics. For instance, with $\varphi = .1$ the model captures about 87% of the output loss experienced by the euro area during the two years following the 2008 financial crisis, while under the benchmark parametrization the output loss in the model is around 24% of that observed in the data.[38]

There are also some aspects of the data that the model misses. In particular, the model predicts a faster output recovery that in the data. The slow recovery could be due, at least partly, to the fact that in the euro area the start of the financial crisis seems to coincide with a slowdown in trend growth. In turn, the drop in trend growth can be attributed to the factors emphasized by the secular stagnation literature, such as

---

37. Concerning the behavior of real wages during the crisis, a caveat is in order. Part of the rise in real wages in the data can be explained with a composition effect, i.e. with low-skilled workers dropping out of employment disproportionally more than high-skilled ones. Since this composition effect is not present in the model, one would want to compare the model with wage series that control for it. However, I could not find an analysis of the behavior of wages during the crisis in the euro area that takes into account this composition effect.

38. To obtain an estimate of the cumulative output loss experienced by the euro area, I computed for every quarter between 2008Q4 and 2010Q3 the output loss as the log-deviation of detrended per capita GDP from its value in 2008Q3. Summing up gives a cumulative output loss equal to 41.7% of 2008Q3 GDP per capita.
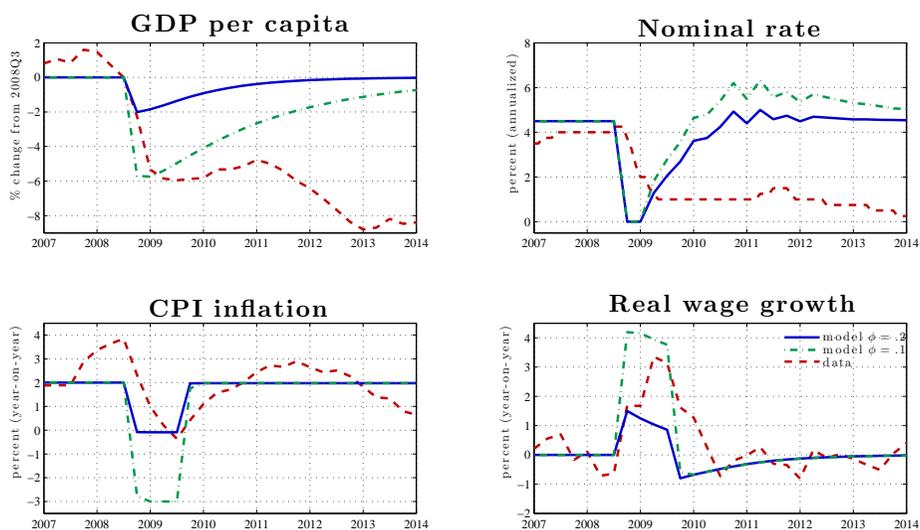
FIGURE 10. Comparison with euro area response to 2008 financial crisis. Notes on data: GDP per capita is detrended by subtracting a log-linear trend calculated over the period 1991Q1-2015Q4. The nominal rate is the ECB discount rate. CPI refers to the euro area Harmonized Index of Consumer Prices. Real wage is the nominal hourly labor cost divided by the CPI. Online Appendix E provides details on the construction of the series.

lower population and labor force growth (Eggertsson and Mehrotra, 2014), or lower productivity growth, perhaps due to hysteresis effects through which a period of low aggregate demand results in weak productivity growth (Benigno and Fornaro, 2015). These same factors might explain why in the model the nominal interest rate rises soon after the start of the crisis, while, as of summer 2017, the ECB policy rate has remained close to zero since 2009Q1. In fact, as highlighted by Eggertsson and Mehrotra (2014) and Benigno and Fornaro (2015), the same slow-moving forces depressing trend growth in the euro area might have lowered the natural interest rate. Finally, the model does not capture the recession that started in 2011Q1. This is unsurprising, since the 2011 recession has been associated with the emergence of turmoil on the sovereign debt markets, an element from which the model abstracts.

Overall, this exercise shows that in a monetary union a reasonably calibrated deleveraging shock generates a significant aggregate recession, at least qualitatively in line with the dynamics observed in the euro area in the two years following the 2008 financial crisis. An important question, to which now I turn, is whether the recession generates significant welfare losses, and how these welfare losses are distributed across the different countries.

5.3. Welfare

In this section, I provide an estimate of the welfare losses associated with deleveraging in a monetary union. Specifically, I calculate the difference in welfare during the transition between the monetary union and the baseline model of Section 2. The baseline model is an interesting benchmark because, as shown in Online Appendix F, it corresponds to the noncooperative constrained-efficient allocation. In other words, the baseline model is isomorphic to an economy in which country-level policymakers, endowed with enough instruments to offset the distortions due to nominal rigidities, implement the noncooperative optimal policy.[39]

More precisely, I compute the welfare losses associated with the monetary union as the proportional increase in consumption for all possible future histories that agents living in a monetary union must receive, in order to be indifferent between remaining in the monetary union and switching to the baseline frictionless economy. Since I am studying a single crisis event, following Gertler and Karadi (2011), I calculate the present value of the consumption-equivalent benefits and normalize them by consumption in the initial steady state.[40]

As reported in Table 3, the mean welfare loss associated with deleveraging in the monetary union is equal to 9.8% of one-period consumption in the initial steady state. Perhaps unsurprisingly, the welfare losses are concentrated in high-debt economies. For instance, countries at the 5th and 10th percentile of the initial net foreign asset distribution suffer losses respectively equal to 52.4% and 13.4% of their consumption in the initial steady state. Instead, the losses experienced by unconstrained countries are very small. Interestingly, the welfare losses follow a U-shaped pattern with respect to the initial stock of net foreign assets held by a country. This is due to the fact that the countries at the extremes of the net foreign asset distribution are the ones

---

39. Of course, there might be gains from cooperation, and hence the allocation reached in the baseline model might not correspond to the cooperative constrained-efficient allocation.

40. Formally, for every country i the welfare losses η_i are defined as

$$E_0\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{\left((1+\eta_i)C_{i,t}^{mu}\right)^{1-\gamma}-1}{1-\gamma}-\frac{\left(L_{i,t}^{mu}\right)^{1+\psi}}{1+\psi}\right)\right]=E_0\left[\sum_{t=0}^{\infty}\beta^t\left(\frac{\left(C_{i,t}^{bas}\right)^{1-\gamma}-1}{1-\gamma}-\frac{\left(L_{i,t}^{bas}\right)^{1+\psi}}{1+\psi}\right)\right],$$

where the superscripts *mu* and *bas* refer to the allocations respectively under the monetary union and the baseline frictionless model, while

$$L_{i,t}^{mu}\equiv\left((1-(1-\varphi)^t)\left(L_{i,t}^{in}\right)^{1+\psi}+(1-\varphi)^t\left(L_{i,t}^{un}\right)^{1+\psi}\right)^{\frac{1}{1+\psi}},$$

where $L_{i,t}^{in}$ and $L_{i,t}^{un}$ denote the labor supply of members of respectively informed and uninformed unions. The normalized present value of the consumption equivalent benefits is then defined as

$$\frac{E_0\left[\sum_{t=0}^{\infty}\beta^t\eta_iC_{i,t}^{mu}\right]}{C_i}\cdot 100,$$

where C_i denotes consumption in the initial steady state. Table 4 in Online Appendix G reports the corresponding values of the consumption equivalents η_i.

TABLE 3. Welfare losses (% of quarterly steady state consumption).

	Mean	5th perc.	10th perc.	25th perc.	50th perc.	75th perc.
Benchmark	9.8	52.4	13.4	0.4	0.6	0.7
$\bar{\pi} = 1.04^{1/4}$	8.7	42.7	8.9	0.6	1.3	1.4
Transfer	6.5	29.9	2.7	-1.2	0.7	2.4

Notes: The welfare losses are computed as the proportional increase in consumption for all possible future histories that agents living in a monetary union must receive, in order to be indifferent between remaining in the monetary union and switching to the baseline frictionless economy. The consumption-equivalent benefits are expressed as percentage of consumption in the initial steady state.

that experience the largest adjustment in real wages in the baseline model. Hence, for these countries nominal wage rigidities represent a particularly severe friction in the adjustment to the deleveraging shock.

These results imply that the frictions associated with a monetary union, that is the inability to adjust exchange rates across member countries and to set the nominal interest rate below zero, generate substantial welfare losses. In the next sections I discuss some examples of policies that can mitigate the negative impact of deleveraging on welfare, in order to illustrate how the model can be used to evaluate policy interventions.

5.4. Raising the inflation target

One policy that can mitigate the recession during debt deleveraging consists in adopting a higher inflation target. In fact, a higher inflation target relaxes the zero lower bound constraint, giving more room for monetary policy to lower the interest rate in response to the deleveraging shock. Figure 11 compares two monetary unions with different steady state inflation targets.[41] The solid lines refer to an economy with a high inflation target, of 4% per year, while the dashed lines refer to the baseline economy with an annual inflation target of 2%. Clearly, a higher inflation target reduces the drop in output associated with deleveraging. In fact, doubling the inflation target from 2% to 4% per year reduces the aggregate cumulative output losses in the two years following the deleveraging shock from 10.1% to 3.4% of GDP in the initial steady state. This happens because in the high inflation target scenario the central bank is able to cut the real rate by about 200 basis points more compared to the benchmark inflation target.

Table 3 shows the impact on welfare associated with a higher inflation target. On average, the impact on welfare from having a higher inflation target is positive,

---

41. This section looks at two economies whose steady state inflation target is different. An alternative would be to consider a change in the inflation target in response to the tightening of the borrowing limit. However credibility issues are likely to prevent a central bank from changing the inflation target in the middle of a deleveraging episode. This point is discussed by Eggertsson (2008), who considers credibility issues faced by the FED during the Great Depression.
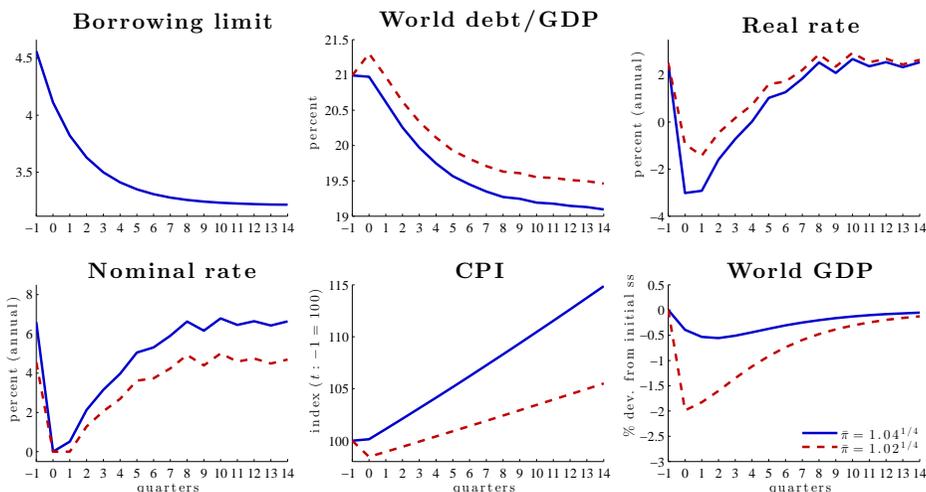
FIGURE 11. Higher inflation target. Notes: world debt refers to world gross debt, defined as $\int_{-\kappa_t}^{0} B_{i,t+1}/R_t di$. World GDP and consumption are respectively defined as $\int_0^1 Y_{i,t}^T + p^N Y_{i,t}^N di$ and $\int_0^1 C_{i,t}^T + p^N C_{i,t}^N di$, where p^N denotes the unconditional mean of $p_{i,t}^N$ in the initial steady state. CPI is the average consumer price index.

since the mean welfare loss is lower in the high inflation target economy that in the benchmark. However, not all countries benefit from a higher inflation target. In fact, while high-debt countries are better off in the high inflation target economy, the opposite is true for wealthy unconstrained countries. One possible explanation for this fact is that a higher inflation target generates a larger drop in the real interest rate during the transition. This has a negative impact on wealthy countries, because it reduces the return that they enjoy on their wealth.

5.5. *Transfers within members of the monetary union*

One policy that has been much discussed in the context of the euro area crisis concerns transfers among members of a monetary union.[42] In this section I perform a simple experiment to evaluate the macroeconomic impact of transfers from creditor to debtor countries. I consider a scenario in which at the start of period 0 every debtor country receives a transfer equal to 1.8% of its external debt. This transfer is financed by creditors countries, and each creditor country contributes with a sum equal to 1.8% of its stock of assets.[43] The size of the transfer is chosen so that the high-debt countries directly constrained by the new borrowing limit, which can be interpreted as the model

---

42. See Farhi and Werning (2017) for an insightful analysis of optimal fiscal transfers inside monetary unions.

43. This transfer scheme captures a variety of policies, such as fiscal transfers inside a monetary union or debt relief policies. This experiment also captures some of the aspects of the public flows passing via
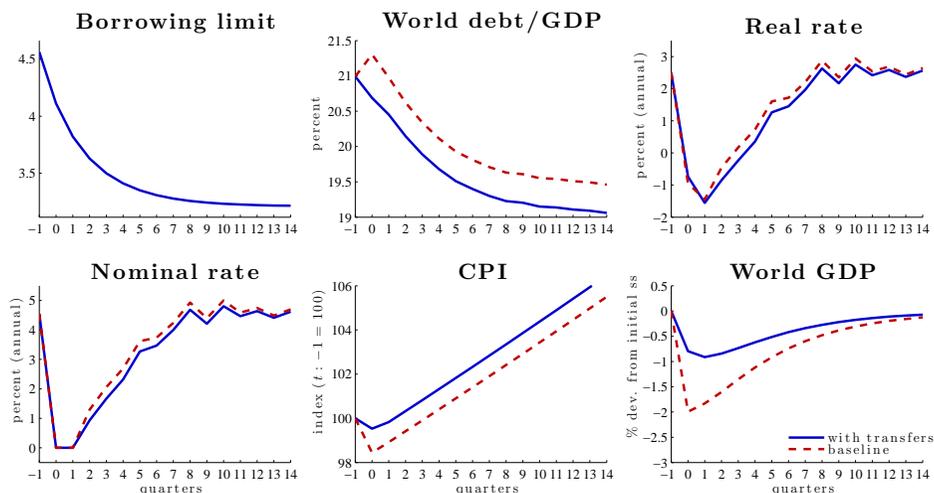
FIGURE 12. Transfers within members of the monetary union. Notes: world debt refers to world gross debt, defined as $\int_{-\kappa_t}^{0} B_{i,t+1}/R_t\,di$. World GDP and consumption are respectively defined as $\int_0^1 Y_{i,t}^T + p^N Y_{i,t}^N\,di$ and $\int_0^1 C_{i,t}^T + p^N C_{i,t}^N\,di$, where p^N denotes the unconditional mean of $p_{i,t}^N$ in the initial steady state. CPI is the average consumer price index.

counterpart of GIPS countries, receive on average a transfer equal to 1% of their annual GDP in the initial steady state.[44]

The results are shown in Figure 12. The solid lines refer to the economy with transfers, while the dashed lines refer to the baseline economy. Figure 12 makes clear that transfers from creditor to debtors countries reduce deflation and the output contraction. This happens because debtor countries have a higher propensity to consume out of income than creditor countries. Hence, transfers toward debtor countries stimulate aggregate demand. In turn, the increase in aggregate demand has a positive impact on output, because the recession during the liquidity trap is due to weak aggregate demand. Quantitatively, even a relatively modest transfer such as the one considered in this section can have a significant impact on output. For instance, the transfer scheme considered in this experiment reduces the cumulative loss in output during the two years after the deleveraging shock from 10.1% to 5.2% of steady state output.

---

the ECB which played a major role in cushioning the fall in foreign credit in the countries at the eurozone periphery in the first phase of the 2008/2009 recession, as shown by Lane and Milesi-Ferretti (2012).

44. For comparison, Feyrer and Sacerdote (2013) estimate that among US states roughly 0.25% of every 1% change in GDP is offset by federal transfers. Under the transfer scheme assumed in this experiment, the model implies that the deleveraging shock produces an average output loss among constrained countries of about 8.5% of annual steady state GDP. This means that, under a transfer scheme similar to the one in place across US states, constrained countries would receive on average a transfer equal to 1.25% of their annual steady state GDP, just a bit higher than the 1% assumed in the experiment.

As reported in Table 3, the transfer scheme has on average a positive impact on welfare. The welfare gains are, however, unevenly distributed. In general debtor countries, captured in the table by the countries from the 5th to the 50th percentile of the initial debt distribution, gain from the transfer scheme. In fact, these countries enjoy both a direct welfare gain from the transfer, and an indirect gain coming from the boost in aggregate demand generated by the transfer. Creditor countries, captured in the table by the 75th percentile country, tend to experience a welfare loss. In fact, in these countries the benefits coming from higher aggregate demand are not sufficiently big to compensate the wealth loss implied by the transfer scheme.

This experiment suggests that transfers from creditor to debtor countries of a monetary union can play a role in mitigating the recession associated with an episode of debt deleveraging. These transfers, however, might entail welfare losses in wealthy countries, and hence be hard to implement from a political perspective.

6. Conclusion

I propose a multi-country model for understanding deleveraging among a group of financially integrated countries. The model highlights the channels through which participation in a monetary union impede a smooth adjustment to deleveraging. Deleveraging leads to a drop in the world interest rate, both because high-debt countries are forced to save more in order to reduce their debt and because the rest of the world experiences an increase in the desire to accumulate precautionary savings. In the absence of nominal rigidities, deleveraging also triggers a rise in production in high-debt countries. If wages are nominally rigid but nominal exchange rates are allowed to float, the rise in production involves a nominal depreciation in high-debt countries. In a monetary union, the combination of nominal wage rigidities and fixed exchange rates prevents any increase in production in indebted countries. This amplifies the fall in the world consumption demand and the drop in the world interest rate. Hence, monetary unions are prone to enter a liquidity trap during an episode of deleveraging. In a liquidity trap deleveraging generates a deflationary union-wide recession, hitting high-debt countries especially hard.

The analysis presented in this paper can be extended in a number of directions. First, the model could be used to investigate a richer menu of policies. In particular, the recent experience of the euro area has sparked a lively debate on the role of fiscal policy inside monetary unions, and the model has the potential to shed light on this key policy issue. In addition, it would be interesting to consider collateral constraints in which asset prices play a role in determining access to credit. For instance, Fornaro (2015) and Ottonello (2013) study the interactions between collateral constraints and exchange rate policy in small open economies. An open research question concerns the interactions between these types of constraints and the zero lower bound in a model of the world economy.

References

Aiyagari, Rao (1994). "Uninsured Idiosyncratic Risk and Aggregate Saving." *Quarterly Journal of Economics*, 109(3), 659–684.

Bai, Yan and Jing Zhang (2010). "Solving the Feldstein–Horioka Puzzle with Financial Frictions." *Econometrica*, 78(2), 603–632.

Barattieri, Alessandro, Susanto Basu, and Peter Gottschalk (2014). "Some Evidence on the Importance of Sticky Wages." *American Economic Journal: Macroeconomics*, 6(1), 70–101.

Benigno, Gianluca, Nathan Converse, and Luca Fornaro (2015). "Large Capital Inflows, Sectoral Allocation, and Economic Performance." *Journal of International Money and Finance*, 55, 60–87.

Benigno, Gianluca and Luca Fornaro (2015). "Stagnation Traps." *Review of Economic Studies*, forthcoming.

Benigno, Pierpaolo (2004). "Optimal Monetary Policy in a Currency Area." *Journal of International Economics*, 63(2), 293–320.

Benigno, Pierpaolo and Federica Romei (2014). "Debt Deleveraging and the Exchange Rate." *Journal of International Economics*, 93(1), 1–16.

Bernanke, Ben S. and Kevin Carey (1996). "Nominal Wage Stickiness and Aggregate Supply in the Great Depression." *Quarterly Journal of Economics*, 111(3), 853–883.

Bewley, Truman F. (1977). "The Permanent Income Hypothesis and Welfare Economics." *Journal of Economics Theory*, 16(2), 252–292.

Braggion, Fabio, Lawrence J. Christiano, and Jorge Roldos (2007). "Optimal Monetary Policy in a Sudden Stop." *Journal of Monetary Economics*, 56(4), 582–595.

Castro, Rui (2005). "Economic Development and Growth in the World Economy." *Review of Economic Dynamics*, 8(1), 195–230.

Cespedes, Luis F., Roberto Chang, and Andres Velasco (2004). "Balance Sheets and Exchange Rate Policy." *American Economic Review*, 94(4), 1183–1193.

Chang, Yongsung, Sun-Bin Kim, and Jaewoo Lee (2013). "Accounting for Global Dispersion of Current Accounts." *Review of Economic Dynamics*, 16, 477–496.

Christiano, Lawrence J., Christopher Gust, and Jorge Roldos (2004). "Monetary Policy in a Financial Crisis." *Journal of Economic Theory*, 119(1), 64–103.

Clarida, Richard H. (1990). "International Lending and Borrowing in a Stochastic, Stationary Equilibrium." *International Economic Review*, 31(3), 543–558.

Cook, David (2004). "Monetary Policy in Emerging Markets: Can Liability Dollarization Explain Contractionary Devaluations?" *Journal of Monetary Economics*, 51(6), 1155–1181.

Devereux, Michael B., Philip R. Lane, and Juanyi Xu (2006). "Exchange Rates and Monetary Policy in Emerging Market Economies." *Economic Journal*, 116(511), 478–506.

Eggertsson, Gauti (2008). "Great Expectations and the End of the Depression." *American Economic Review*, 98(4), 1476–1516.

Eggertsson, Gauti and Paul Krugman (2012). "Debt, Deleveraging, and the Liquidity Trap: a Fisher-Minsky-Koo Approach." *Quarterly Journal of Economics*, 127(3), 1469–1513.

Eggertsson, Gauti and Neil Mehrotra (2014). "A Model of Secular Stagnation." NBER Working Paper No. 20574.

Eichengreen, Barry (1998). *Globalizing Capital: a History of the International Monetary System*. Princeton University Press.

Eichengreen, Barry and Jeffrey Sachs (1985). "Exchange Rates and Economic Recovery in the 1930s." *Journal of Economic History*, 45(4), 925–946.

Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin (2000). "Optimal Monetary Policy with Staggered Wage and Price Contracts." *Journal of Monetary Economics*, 46(2), 281–313.

Fabiani, Silvia, Claudia Kwapil, Tairi Rõõm, Kamil Galuscak, and Ana Lamo (2010). "Wage Rigidities and Labor Market Adjustment in Europe." *Journal of the European Economic Association*, 8(2-3), 497–505.

Farhi, Emmanuel, Gita Gopinath, and Oleg Itskhoki (2014). "Fiscal Devaluations." *Review of Economic Studies*, 81(2), 725–760.

Farhi, Emmanuel and Ivan Werning (2017). "Fiscal Unions." *American Economic Review*, forthcoming.

Fehr, Ernst and Lorenz Goette (2005). "Robustness and Real Consequences of Nominal Wage Rigidity." *Journal of Monetary Economics*, 52(4), 779–804.

Feyrer, James and Bruce Sacerdote (2013). "How Much Would US Style Fiscal Integration Buffer European Unemployment and Income Shocks? (A Comparative Empirical Analysis)." *American Economic Review*, 103(3), 125–128.

Flodén, Martin (2008). "A Note on the Accuracy of Markov-Chain Approximations to Highly Persistent AR(1) Processes." *Economics Letters*, 99(3), 516–520.

Fornaro, Luca (2015). "Financial Crises and Exchange Rate Policy." *Journal of International Economics*, 95(2), 202–215.

Galí, Jordi (2009). *Monetary Policy, Inflation, and the Business Cycle: An Introduction to the New Keynesian Framework*. Princeton University Press.

Galí, Jordi and Tommaso Monacelli (2005). "Monetary Policy and Exchange Rate Volatility in a Small Open Economy." *Review of Economic Studies*, 72(3), 707–734.

Galí, Jordi and Tommaso Monacelli (2016). "Understanding the Gains from Wage Flexibility: The Exchange Rate Connection." *American Economic Review*, 106(12), 3829–3868.

Gertler, Mark, Simon Gilchrist, and Fabio M. Natalucci (2007). "External Constraints on Monetary Policy and the Financial Accelerator." *Journal of Money, Credit and Banking*, 39(2-3), 295–330.

Gertler, Mark and Peter Karadi (2011). "A Model of Unconventional Monetary Policy." *Journal of Monetary Economics*, 58(1), 17–34.

Gottschalk, Peter (2005). "Downward Nominal-Wage Flexibility: Real or Measurement Error?" *Review of Economics and Statistics*, 87(3), 556–568.

Guerrieri, Veronica and Guido Lorenzoni (2017). "Credit Crises, Precautionary Savings, and the Liquidity Trap." *Quarterly Journal of Economics*, 132(3), 1427–1467.

Huggett, Mark (1993). "The Risk-Free Rate in Heterogeneous-Agent Incomplete-Insurance Economies." *Journal of Economic Dynamics and Control*, 17(5-6), 953–969.

Lane, Philip R. (2012). "The European Sovereign Debt Crisis." *Journal of Economic Perspectives*, 26(3), 49–67.

Lane, Philip R. and Gian Maria Milesi-Ferretti (2007). "The External Wealth of Nations Mark II: Revised and Extended Estimates of Foreign Assets and Liabilities, 1970-2004." *Journal of International Economics*, 73(2), 223–250.

Lane, Philip R. and Gian Maria Milesi-Ferretti (2012). "External Adjustment and the Global Crisis." *Journal of International Economics*, 88(2), 252–265.

Mankiw, Gregory and Ricardo Reis (2002). "Sticky Information Versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve." *Quarterly Journal of Economics*, 117(4), 1295–1328.

Martin, Alberto and Jaume Ventura (2012). "Economic Growth with Bubbles." *American Economic Review*, 102(6), 3033–3058.

Martin, Philippe and Thomas Philippon (2017). "Inspecting the Mechanism: Leverage and the Great Recession in the Eurozone." *American Economic Review*, 107(7), 1904–1937.

McKinsey, Global Institute (2010). "Debt and Deleveraging: The Global Credit Bubble and its Economic Consequences."

McKinsey, Global Institute (2012). "Debt and Deleveraging: Uneven Progress on the Path to Growth."

Mian, Atif, Kamalesh Rao, and Amir Sufi (2013). "Household Balance Sheets, Consumption, and the Economic Slump." *Quarterly Journal of Economics*, 128(4), 1687–1726.

Mian, Atif and Amir Sufi (2014). "What Explains the 2007–2009 Drop in Employment?" *Econometrica*, 82(6), 2197–2223.

Mody, Ashoka, Franziska Ohnsorge, and Damiano Sandri (2012). "Precautionary Savings in the Great Recession." *IMF Economic Review*, 60(1), 114–138.

Ottonello, Pablo (2013). "Optimal Exchange Rate Policy Under Collateral Constraints and Wage Rigidity." Columbia University working paper.

Schmitt-Grohé, Stephanie and Martin Uribe (2016). "Downward Nominal Wage Rigidity, Currency Pegs, and Involuntary Unemployment, Stephanie Schmitt-Grohé and Martín Uribe." *Journal of Political Economy*, 124, 1466–1514.

Shambaugh, Jay C. (2012). "The Euro's Three Crises." *Brookings Papers on Economic Activity*, 2012(1), 157–231.

Tauchen, George and Robert Hussey (1991). "Quadrature-Based Methods for Obtaining Approximate Solutions to Nonlinear Asset Pricing Models." *Econometrica*, 59(2), 371–396.

Werning, Ivan (2011). "Managing a Liquidity Trap: Monetary and Fiscal Policy." NBER Working Paper No. 17344.