On the Inefficiency of Financial Market Equilibria in Macroeconomic Models with Nominal Rigidities

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We study economies with nominal rigidities in goods and labor markets and consider government interventions in financial markets. Our general second-best theory establishes that equilibria with nominal rigidities are generically inefficient, even when markets are complete. The inefficiency is due to an aggregate demand externality. We obtain a formula for optimal interventions that gives insight into the direction of interventions. We provide a number of applications of our general theory, such as macroprudential policies guarding against deleveraging and liquidity traps, capital controls due to fixed exchange rates or liquidity traps and fiscal transfers within a currency union.

1 Introduction

The Arrow-Debreu construct assumes complete, competitive markets and delivers an ideal benchmark with first-best efficient outcomes. Economists have explored a plethora of frictions or departures from Arrow-Debreu's assumptions, opening the door to inefficient outcomes. These models may justify government interventions, for example guaranteeing a Pareto improvement, even if policy instruments are coarse and imperfect and fall short of reestablishing the first-best outcome. The study of second-best policies, constrained by a model's frictions and the available policy tools, is a fruitful active area of research and has yielded important insights into taxation, insurance, macroeconomic stabilization, industrial regulation, and many other issues.

A large part of macroeconomic thinking and modeling is dominated by a particular friction: nominal rigidities. When prices and wages are constrained so that they can only adjust slowly, the equilibrium outcome is inefficient, potentially resembling economic slumps and booms. They also imply that monetary policy and shocks are non-neutral. The centrality of nominal rigidities is often traced back to John Maynard Keynes, but it was also embraced by Milton Friedman (e.g. Friedman, 1953); it is embodied in early macroeconomic models, in the disequilibrium literature of the 1970s (e.g. Barro and Grossman, 1971) and in the recent and large New-Keynesian literature featuring monopolistic competition.

This goal of this paper is to offer a general theory, capable of encompassing a range of important applications, establishing that interventions in financial markets can be generically Pareto improving in models with nominal rigidities in goods and labor markets, of the kind often assumed in macroeconomic models. We approach this endeavor in a way that parallels Geanakoplos and Polemarchakis (1985). They established that if asset markets are incomplete, then financial market equilibria are generically *constrained* inefficient;[1] similar results are obtained in economies with private information or borrowing constraints (see e.g. Greenwald and Stiglitz, 1986). In contrast, we assume that asset markets are complete, but establish that financial market equilibria are generically *constrained* inefficient when there are nominal rigidities in goods or labor markets.

By constrained inefficiency we mean, in both cases, that the planner does not necessarily have the tools necessary to entirely overcome the frictions leading to inefficiencies. For example, in our applications the policy instruments can be interpreted as taxes or regulation on borrowing or portfolio decisions. It is also important that monetary policy be constrained and unable to overcome the nominal rigidities. In some applications it is also important that tax instruments be somewhat constrained, to avoid being able to control all relative prices and effectively undo the price rigidities.

Although we share the focus on constrained inefficiency with the pecuniary externality literature, as well as the effort to provide a general theory that encompasses many applications, the source of our results is completely different. The key friction is their

[1] The source of the constrained inefficiency can be understood by the earlier work by Stiglitz (1982). Stiglitz showed that when asset markets are incomplete and there is more than one commodity then redistributions of asset holdings induce relative price changes in each state of the world. These relative price changes, in turn, affect the spanning properties of the limited existing set of assets. This "pecuniary externality" is not internalized by competitive agents, but can be used by the planner to improve the equilibrium outcome. Stiglitz showed that strong assumptions, such as homothetic preferences, are required to guarantee efficiency, suggesting that the conditions needed for efficiency are of a knife edge nature. Geanakoplos and Polemarchakis used transversality theory to formally establish that the set of economies for which the equilibria are constrained inefficient is generic.

framework is market incompleteness; we assume complete markets. Their results rely on price movements inducing pecuniary externalities; in our framework price rigidities negate such effects. Our results are instead driven by macroeconomic externalities which one might label Keynesian aggregate demand externalities.

We do not stop at establishing constrained inefficiency. We also provide a useful formula for the optimal policy that offers insight into the direction of the best intervention. The formula delivers the implicit taxes needed in financial markets as a function of primitives and sufficient statistics. In particular, within each state of the world there is a sub-equilibrium in goods and labor markets affected by nominal rigidities. One can define *wedges* that measure the departure of these allocations from the first best outcome. In simple cases, a positive wedge for a particular good indicates the under-provision of this good. Our formula shows that wedges and income elasticities play a key role determining the optimal direction of financial market interventions. In particular, state contingent payments should be encouraged for agents and states that tend to expand the consumption of goods that feature a larger wedge. This is because their additional demand helps to mitigate the prevailing market inefficiency in that state.

We illustrate our result by drawing on a number of important applications. We provide four example applications, two novel ones and two that have appeared earlier in our own work. All these applications can be seen as particular cases of our general model.

Our first application is motivated by Eggertsson and Krugman (2012) and Guerrieri and Lorenzoni (2011). These authors emphasize that episodes with household deleveraging can throw the economy into a liquidity trap. In Eggertsson and Krugman's model, a fraction of households are indebted and are suddenly required to pay down their debts. The effect of this deleveraging shock acts similarly to the introduction of forced savings and pushes equilibrium real interest rates down. If the effect is strong enough then, in a monetary economy, it triggers hitting the zero lower bound on nominal interest rates, leading to a liquidity trap with depressed consumption and output.

To capture this situation we extend the original Eggertsson and Krugman model to include earlier periods before the deleveraging shock, where initial borrowing and savings decisions are made. This captures the credit boom phase, building up debt towards the crisis.Our main result in this context emphasizes *ex ante* macroprudential policies. The optimal intervention lowers the build up in debt during the credit boom. Lower debt mitigates, or potentially avoids altogether, the problem generated by the liquidity trap. Intuitively, individual borrowers do not internalize the harm that their debt have in the ensuing crisis. Debt creates a Keynesian aggregate demand externality. Optimal policy seeks to correct this externality by either imposing Pigouvian taxes that help agents internalize their debt decisions, or by imposing quantity restrictions on borrowing.

Our second application also involves the zero lower bound on interest rates, but does so in an international context that allows us to focus on exchange rate policy and the use of capital controls on inflows. Imagine a country or region that borrows, knowing that it may be latter hit by a sudden stop. A sudden stop in this context amounts to a deleveraging shock at the country level, requiring a dramatic fall in total debt against the rest of the world. In our model, there are traded and non traded goods, so that we may speak of a real exchange rate associated with their relative price. The government controls the nominal exchange rate and may also impose capital controls.

During the credit boom consumption and output rise and the real exchange rate is appreciated; during the sudden stop phase the reverse is true; after the sudden stop, the exchange rate is expected to recover and appreciate. In other words, during the sudden stop there is a need for a temporary depreciation. Given that prices are rigid, these movements in the real exchange rate are best accomplished by movements in the nominal exchange rate. By the interest rate parity condition with the rest of the world, during the sudden stop the expected nominal appreciation pushes the domestic nominal interest rate down.

As long as these effects are small, so that the nominal interest rate remains positive, optimal policy involves fluctuations in the nominal exchange rate and no capital controls. Thus, in dealing with this sudden stop shock, the exchange rate is the first line of response, echoing the importance of exchange rates adjustments advocated by Friedman (1953).

However, when these effects are large enough, the nominal interest rate is pushed to zero and monetary policy becomes constrained. We show that in these cases *ex ante* capital controls on inflows which mitigate the country's borrowing are optimal.

Our other two example applications draw on our previous work in Farhi and Werning (2012a) and Farhi and Werning (2012b).[2] Both are also set in an open economy context, but focus on situations where monetary policy is constrained at the outset by a fixed exchange rate, the main motivation being for countries that form part of a currency union. The first of these examples draws on Farhi and Werning (2012a) and Schmitt-Grohe and Uribe (2012) to capture Mundell's Trilemma. We find that it is optimal to use capital controls in a context with fixed exchange rates to regain autonomy of monetary policy. Taxes on inflows are deployed when the economy is booming to cool it down; conversely, taxes

[2] To avoid overextending ourselves, we stop short of developing and explaining these two applications in full. We provide stylized versions of the basic models and results that are enough to appreciate the unifying aspects emphasized by the general approach taken in the present paper. However, Farhi and Werning (2012a) and Farhi and Werning (2012b) address a number of specific issues that arise in these applications using a richer model.

on outflows help mitigate recessions. Our final example application draws on Farhi and Werning (2012b) to address the design of a fiscal union within a currency union. Our results indicate that transfers across countries must be designed taking into account the impact of these risk sharing arrangements on the macroeconomy. Private agents will not internalize aggregate demand externalities. Thus, even with integrated complete financial markets the competitive equilibrium is not optimal and government intervention is required. This forms the basis for a case for fiscal unions within a currency union.

Related Literature. TO BE COMPLETED

2 Model

Agents are indexed by $i \in I$. We use two indices to index goods (j, s) with $j \in J_s$ and $s \in S$. In some of our applications, $s \in S$ will denote a state of the world, and goods $j \in J_s$ will denote different goods in different periods. In some other applications, states $s \in S$ will denote periods and goods $j \in J_s$ will denote different goods. We introduce this distinction between j and s for the following reason. We will assume that the government has the ability to use tax instruments (or equivalently to impose quantity restrictions) to affect spending decisions along the $s \in S$ dimension but not along the $j \in J_s$ dimension.

The preferences of agent i are given by

$$\sum_{s \in S} U^i(\{X^i_{j,s}\}; s)\pi(s).$$

The production possibility set is described by a production function

$$F(\{Y_{j,s}\}) \leq 0. \tag{1}$$

Our goal is to characterize the implications of price rigidities in goods markets for the efficiency of private risk sharing decisions in asset markets. To do so, we confront agent i with the following budget constraints

$$\sum_{s \in S} D^i_s Q_s \leq 0,$$

where for all $s \in S$

$$\sum_{j \in J_s} P_{j,s} X^i_{j,s} \leq -T^i_s + \Pi^i_s + (1 + \tau^i_{D,s}) D^i_s.$$

The first budget constraint encodes how the agent can transfer wealth along the $s \in S$ dimension, according to state prices Q_s. The second budget constraint then determines the income available to the agent to spend on goods $j \in J_s$ for each s. Importantly, we allow for a portfolio tax $\tau^i_{D,s}$ to influence these portfolio decisions, as well as a lump-sum tax T^i_s. Finally, Π^i_s denotes the share of profits for agent.

For some of our applications, it will be convenient to allow for further restrictions on the consumption bundles available to the agent for a given s

$$\{X^i_{j,s}\} \in B^i_s,$$

for some set B^i_s. We take these restrictions to be features of the environment. For example, in our applications, they allow us to capture borrowing constraints. Of course we can take B^i_s to be the domain of the utility function, in which case there are no further restrictions on consumption.

It will be useful to introduce the indirect utility function of agent i for a given s as

$$V^i_s(I^i_s, P_s) = \max U^i(\{X^i_{j,s}\}; s)$$

subject to

$$\sum_{j \in J_s} P_{j,s} X^i_{j,s} \leq I^i_s,$$

$$\{X^i_{j,s}\} \in B^i_s.$$

We denote by

$$X^i_{j,s} = X^i_{j,s}(I^i_s, P_s) \tag{2}$$

the associated Marshallian demand functions and by

$$S^i_{k,j,s} = X^i_{P_k,j,s} + X^i_{k,s} X^i_{I,j,s}$$

the associated Slutsky matrix.

We capture the rigidity of prices through the following feasible price set

$$\Gamma(\{P_{j,s}\}) \leq 0, \tag{3}$$

where Γ is a vector. This formulation allows us to capture very general forms of nominal rigidities. It also allows us to capture situations where certain prices are given (think of a small open economy).

We postpone the precise description of the market structure that leads to these prices. For now, we proceed in a way similar to the seminal analysis of Diamond and Mirrlees (1971) and assume that the all production possibilities can be controlled by the government. Their goal was to characterize arrangements where agents interact in decentralized markets and the government seeks to achieve some redistributive objective or to raise some revenues. They were led to a second best problem because they assumed that the government could only use a restricted set of instruments, linear commodity taxes. They ruled out poll taxes which would allow the government to achieve its objectives without imposing any distortion, thereby reaching the first best. We are interested in a different set of constraints, namely nominal rigidities in the prices faced by consumers. We also incorporate restrictions on instruments, but of a different kind. In particular, we allow poll taxes, but rule out a complete set of commodity taxes that would allow the government to get around the nominal rigidities and reach the first best.

In our applications, we propose explicit decentralizations where production is undertaken by firms who post prices subject to nominal rigidities. More precisely, in all our applications, we assume that goods are produced under monopolistic competition from labor. Firms post prices, and accommodate demand at these prices. The prices posted by firms cannot be fully adjusted across time periods or states of the world. Sometimes, we will interpret states s as periods, or different goods j within a state s as the same underlying good but in different periods. Our formulation of nominal rigidities allows us to capture all these different cases. Importantly, we assume that the government can influence the prices set by these firms with appropriate labor taxes.

The government must balance its budget

$$\sum_{s\in S} D_s^g Q_s \leq 0,$$

where for all $s \in S$,

$$\sum_{i\in I}(T_s^i - \tau_{D,s}^i D_s^i) + D_s^g = 0.$$

Equilibrium. An equilibrium is then simply characterized by an allocation for consumption $\{X_{j,s}^i\}$, output $\{Y_{j,s}\}$, portfolios $\{D_s^i, D_s^g\}$ as well as prices $\{Q_s\}$ and $\{P_{j,s}\}$ such that agents optimize, price satisfy the nominal rigidity restrictions, the government balances its budget and markets clear so that for all $s \in S$ and $j \in J_s$,

$$Y_{j,s} = \sum_{i\in I} X_{j,s}^i \tag{4}$$

and for all $s \in S$,

$$\sum_{i \in I} \Pi^i_s = \sum_{j \in J_s} P_j Y_{j,s}. \tag{5}$$

This implies that bond markets clear so that for all $s \in S$

$$D^g_s + \sum_{i \in I} D^i_s = 0.$$

Proposition 1 (Implementability)**.** *An allocation for consumption $\{X^i_{j,s}\}$ and output $\{Y_{j,s}\}$ together with prices $\{P_{j,s}\}$ form part of an equilibrium if and only if there are incomes $\{I^i_s\}$ such that* (1)*,* (2)*,* (3) *and* (4) *hold.*

Planning problem. We now solve the Ramsey problem of choosing the equilibrium that maximizes social welfare, computed as a weighted average of agents utilities, with arbitrary Pareto weights λ^i.

We are led to the following planning problem which maximizes a weighted average of utility across agents

$$\max \sum_{i \in I} \sum_{s \in S} \lambda^i V^i_s(I^i_s, P_s), \tag{6}$$

subject to the resource constraints that,

$$F(\{\sum_{i \in I} X^i_{j,s}(I^i_s, P_s)\}) \leq 0,$$

and the price constraint that

$$\Gamma(\{P_{j,s}\}) \leq 0.$$

The first order conditions are that for all $i \in I$ and $s \in S$,

$$\lambda^i V^i_{I,s} = \mu \sum_{j \in J_s} F_{j,s} X^i_{I,j,s},$$

and that for all $s \in S$ and $k \in J_s$,

$$\sum_{i \in I} \lambda^i V^i_{P_k,s} = \sum_{i \in I} \sum_{j \in J_s} \mu F_{j,s} X^i_{P_k,j,s} + \nu \cdot \Gamma_{k,s},$$

where μ is the multiplier on the resource constraint and ν is the (vector) multiplier on the price constraint.

We define the wedges $\tau_{j,s}$ as

$$\frac{P_{j^*(s),s}}{P_{j,s}}\frac{F_{j,s}}{F_{j^*(s),s}} = 1 - \tau_{j,s},$$

for each $s \in S$ given some reference good $j^*(s) \in J_s$. for each These wedges would be equal to zero at the first best.

Using these wedges we can rearrange the first order conditions to derive the following two key equations. For all i and s, we must have

$$\frac{\lambda^i V^i_{I,s}}{1 - \sum_{j \in J_s} \frac{P_{j,s} X^i_{j,s}}{I^i_s} \frac{I^i_s X^i_{I,j,s}}{X^i_{j,s}} \tau_{j,s}} = \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}}, \tag{7}$$

and for all $\omega \in \Omega$, we must have

$$\nu \cdot \Gamma_{k,s} = \sum_{i \in I} \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} \sum_{j \in J_s} P_{j,s} \tau_{j,s} S^i_{k,j,s}. \tag{8}$$

The left hand side of equation (7) defines the right notion of social marginal utility of income and is to be compared with the private marginal utility of income $\lambda^i V^i_{I,s}$. The wedge between the social and the private marginal utility of income is higher when the spending share of consumer i in sectors that have a high wedge, and similarly when the income elasticity of spending consumer i in sectors that have a high wedge is high. Equation (8) characterizes optimal prices P_s (subject to the nominal rigidity constraints) and constrains different weighted averages of the wedge $\tau_{j,s}$. If prices $P_{j,s}$ were flexible and could depend on the state of the world, then it would be possible to achieve $\tau_{j,s} = 0$ for all $j \in J$ and $s \in S$. With nominal rigidities, this outcome cannot be reached in general.

The next proposition computes the portfolio taxes that are required to implement the solution of the social planning problem (6). Portfolio taxes are required because private portfolio decisions are based on the private marginal utility of income instead of the social marginal utility of income. The wedge between private and social marginal utilities justifies government intervention. Intuitively, portfolio decisions reallocate spending along the $s \in S$ dimension. When forming their portfolios, agents do not internalize the macroeconomic stabilization benefits of these spending reallocations. Corrective taxes are required to align private and social incentives.

Proposition 2. *The solution to the planning problem* (6) *can be implemented with portfolio taxes* *given by*

$$1+\tau^i_{D,s} = \frac{1}{1-\sum_{j\in J_s}\frac{P_{j,s}X^i_{j,s}}{I^i_s}\frac{I^i_s X^i_{I,j,s}}{X^i_{j,s}}\tau_{j,s}},$$

where the wedges $\tau_{j,s}$ *must satisfy the weighted average conditions* (8).

This proposition shows that constrained Pareto efficient outcomes—solutions of the planning problem (6) for some set of Pareto weights $\{\lambda^i\}$—can be implemented with portfolio taxes. There are of course equivalent implementations with quantity restrictions (caps and floors on portfolio holdings) instead of price interventions (portfolio taxes), and we use both in our applications, depending on the specific context. Our theory is silent on the relative desirability of one form of intervention over another. We refer the reader to the classic treatment of Weitzman (1974) for some insights into this issue.

Proposition 2 establishes that portfolio taxes are sufficient to implement constrained Pareto efficient outcomes. It does not show that portfolio taxes (or some other equivalent form of government intervention in portfolio decisions) are necessary. Indeed, it is possible that some constrained Pareto efficient outcomes can be decentralized with zero portfolio taxes. We now establish that such outcomes are not generic.

Proposition 3. *Equilibria without portfolio taxes are generically constrained Pareto inefficient.*

Proof. To show generic inefficiency, we apply transversality theory. We consider the (vector valued) function G of I^i_s, $P_{j,s}$, P_ω, μ_s, and parameters (technology and preferences) given by

$$F(\{\sum_{i\in I} X^i_{j,s}(I^i_s, P_s)\}),$$

$$\frac{V^i_{I,s}}{1-\sum_{j\in J_s}\frac{P_{j,s}X^i_{j,s}}{I^i_s}\frac{I^i_s X^i_{I,j,s}}{X^i_{j,s}}\tau_{j,s}} - \frac{1}{\lambda^i}\frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} \qquad \text{for all } i\in I \text{and } s\in S,$$

$$\nu\cdot\Gamma_{k,s} = \sum_{i\in I}\frac{F_{j^*(s),s}}{P_{j^*(s),s}}\sum_{j\in J_s} P_{j,s}\tau_{j,s}S^i_{k,j,s} \qquad \text{for all } s\in S \text{and } k\in J_s,$$

where

$$\frac{P_{j^*(s),s}}{P_{j,s}}\frac{F_{j,s}}{F_{j^*(s),s}} = 1-\tau_{j,s} \qquad \text{for all } j\in J_s \text{and } s\in S.$$

Let $G^{i,i'}_{s,s'}$ be the function given by

$$\frac{1-\sum_{j\in J_s}\frac{P_{j,s}X^i_{j,s}}{I^i_s}\frac{I^i_s X^i_{I,j,s}}{X^i_{j,s}}\tau_{j,s}}{1-\sum_{j\in J_s}\frac{P_{j,s}X^i_{j,s'}}{I^i_s}\frac{I^i_s X^i_{I,j,s'}}{X^i_{j,s'}}\tau_{j,s'}}-\frac{1-\sum_{j\in J_s}\frac{P_{j,s}X^{i'}_{j,s}}{I^i_s}\frac{I^i_s X^{i'}_{I,j,s}}{X^{i'}_{j,s}}\tau_{j,s}}{1-\sum_{j\in J_s}\frac{P_{j,s}X^{i'}_{j,s'}}{I^i_s}\frac{I^i_s X^{i'}_{I,j,s'}}{X^{i'}_{j,s'}}\tau_{j,s'}}.$$

Let $H^{i,i'}_{s,s'}$ be the function given by $[G, G^{i,i'}_{s,s'}]'$ and let H be the function given by $[G, G^{i,i'}_{s,s'}]'$ (where all the functions $G^{i,i'}_{s,s'}$ are stacked).

Then applying transversality theory, it suffices to prove that (generically) at a point where $H(x) = 0$, one of the functions $H^{i,i'}_{s,s'}$ has a full rank Jacobian. This result is easily established. We can actually prove the following stronger result: for all i, i', s and s', (generically) at every point where $H^{i,i'}_{s,s'}(x) = 0$, the Jacobian of $H^{i,i'}_{s,s'}$ has full rank, i.e. $H^{i,i'}_{s,s'} \pitchfork 0$. □

3 Applications

In this section, we propose a number of natural applications of the general principle that we have isolated in Section 2. In all these applications, there are some constraints on macroeconomic stabilization, either because of the zero lower bound or because of fixed exchange rates. These constraints result in macroeconomic externalities in portfolio decisions (borrowing and saving, risk sharing) that must be corrected through government intervention.

3.1 Liquidity Trap and Deleveraging

In this section we show how our insights apply to a liquidity trap model with deleveraging in the spirit of Eggertsson and Krugman (2012). They studied an economy where indebted households were unexpectedly required to pay down their debt. This shock amounts to a form of forced savings that depresses the equilibrium interest rate. If this effect is strong enough it may push the real interest rate that would be prevail with flexible prices to be negative. However, when prices are rigid and the nominal interest rate is bounded below by zero, monetary policy will find itself constrained at this zero bound. A recession ensues, with output and employment below their flexible price levels.

We extend this analysis by considering the pre-crisis determination of indebtedness and policies. In other words, we suppose that the shock is not completely unexpected and consider prudential measures to mitigate the crisis. Indeed, we show that optimal policy limits borrowing ahead of the crisis.

Households. There are three periods $t \in \{0, 1, 2\}$ and two types of agents $i \in \{1, 2\}$ with relative fractions ϕ^i in a population of mass 1. For concreteness it is useful to think of type 1 agents are "savers" and type 2 agents as "borrowers". Periods 1 and 2 are meant to capture in the economy in Eggertsson and Krugman (2012): in period 1 borrowers must delever, lowering the debt they carry into the last period 2 below their preferred level. The additional period 0, is when borrowers contract their initial debt with savers. To keep things simple, we abstract from uncertainty. A more elaborate version of the model, which would yield the same conclusions, would posit that delevaraging is a shock that occurs only with some positive probability.

Agents of type 1 work and consume in every period with preferences

$$V^1 = \sum_{t=0}^{2} \beta^t [u(C_t^1) - v(N_t^1)].$$

Agents of type 2 consume in every period but do not work with preferences

$$V^2 = \sum_{t=0}^{2} \beta^t u(C_t^2).$$

They have an endowment E_s^2 of goods in period s.

Agents of type 1 can borrow and lend subject to the budget constraints

$$P_t C_t^1 + \frac{1}{1+i_t} B_{t+1}^1 \leq W_t N_t^1 + \Pi_t^1 + B_t^1, \tag{9}$$

where B_t^1 represent the nominal bond holdings and of type-1 agents, Π_t are profits, i_t is the period-t nominal interest rate, and W_t is the nominal wage, and we must have $B_3^1 = 0$. Similarly, the budget constraint of type-2 agents is

$$P_t C_t^2 + \frac{1}{1+i_t} B_{t+1}^2 \leq E_t^2 + B_t^2, \tag{10}$$

where we must have $B_3^2 = 0$. In period 1, type-2 agents face a borrowing constraint: they can only pledge a part $\bar{B}_2 < E_2^2$ of their period-2 endowment in period 1. The borrowing constraint imposes the extra requirement that

$$B_2^2 \leq \bar{B}_2. \tag{11}$$

We will be interested in cases where this constraint is binding. This inequality is meant to capture the deleveraging shock. It is best thought as a financial friction arising from contracting imperfections in the economic environment. Absent policy interventions, there is no analogous friction or borrowing constraint for period 0.

Although there is no borrowing constraint in period 0 inherent to the environment, we consider prudential policy interventions that limit borrowing in the initial period. Thus, we suppose that the government selects a maximum debt level $\bar{B}_1$ and imposes

$$B_1^2 \leq \bar{B}_1. \tag{12}$$

This inequality captures regulations that affect the amount of credit extended to borrowers.[3,4] Finally, to avoid redistribution issues we assume that the government can also, by way of lump sum taxes, control the initial debt levels of both agents, B_0^1 and B_0^2.

The households' first order conditions can be written as

$$\frac{1}{1+i_t} = \frac{\beta u'(C_{t+1}^1)}{u'(C_t^1)}, \tag{13}$$

$$\frac{1}{1+i_t} \geq \frac{\beta u'(C_{t+1}^2)}{u'(C_t^2)}, \tag{14}$$

where each inequality holds with equality if the borrowing constraint in period t is slack and

$$\frac{W_t}{P_t} = \frac{v'(N_t^1)}{u'(C_t^1)}. \tag{15}$$

Firms. The final good is produced by competitive firms that combine a continuum of varieties indexed by $j \in [0,1]$ using a constant returns to scale CES technology

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

where $\epsilon > 1$ is the elasticity of substitution between varieties.

[3] We could have also imposed a lower bound on debt, but this will not be relevant in the cases that we are interested in. The borrowing constraint effectively allows us to control the equilibrium level of debt B_1^2.

[4] An alternative formulation that leads to the same results is to tax borrowing to affect the interest rate faced by borrowers.

Each variety is produced monopolistically from labor by a firm with a productivity A_t in period t

$$Y_t(j) = A_t N_t(j).$$

Each monopolist hires labor in a competitive market with wage W_t, but pays $W_t(1+\tau_L)$ net of tax on labor. Firms post prices. We assume an extreme form of price rigidity: prices posted in period 0 remain in effect in all periods. The demand for each variety is given by $C_t(P(j)/P)^{-\epsilon}$ where $P = (\int (P(j))^{1-\varepsilon} dj)^{1/(1-\varepsilon)}$ is the (constant) price index and $C_t = \sum_{i=1}^{2} \phi^i C_t^i$ is aggregate consumption.

Firms seek to maximize the discounted value of profits

$$\max_{P(j)} \sum_{t=0}^{2} \prod_{s=0}^{t-1} \frac{1}{1+i_s} \Pi_t(j),$$

where

$$\Pi_t(j) = \left(P(j) - \frac{1+\tau_L}{A_t} W_t \right) C_t \left(\frac{P(j)}{P} \right)^{-\epsilon}.$$

Aggregate profits are given by $\Pi_t = \int \Pi_t(j) dj$. In a symmetric equilibrium, all monopolists set the same profit maximizing price P, which is a markup over a weighted average across states of the marginal cost across time periods.

$$P = (1+\tau_L) \frac{\varepsilon}{\varepsilon - 1} \frac{\sum_{t=0}^{2} \prod_{s=0}^{t-1} \frac{1}{1+i_s} \frac{W_t}{A_t} C_t}{\sum_{t=0}^{2} \prod_{s=0}^{t-1} \frac{1}{1+i_s} C_t}. \tag{16}$$

And we have $P_t = P$ at every date t.

Government. The government sets the tax on labor τ_L, the borrowing limit $\bar{B}_1$ in period 0, and the nominal interest rate i_t in every period. In addition, it levies lump sum taxes in period 0. Lump sum taxes T^1 and T^2 can differ for agents of type 1 and agents of type 2. The budget constraint of the government is

$$\frac{1}{1+i_t} B_{t+1}^g = B_t^g + \tau_L W_t N_t^1. \tag{17}$$

The lump sum taxes T^1 and T^2 allow the government to achieve any distributive objective between the government B_0^g, type-1 agents B_0^1 and type-2 agents B_0^2, subject to the adding-up constraint

$$B_0^g + B_0^1 + B_0^2 = 0.$$

Equilibrium. An equilibrium specifies consumption $\{C_t^i\}$, labor supply $\{N_t^1\}$, bond holding $\{B_t^i, B_t^g\}$, prices P and wages $\{W_t\}$, nominal interest rates $\{i_t\}$, the borrowing limit $\bar{B}_1$, the labor taxes τ_L such that households and firms maximize, the government's budget constraint is satisfied, and markets clear:

$$\sum_{i=1}^{2} \phi^i C_t^i = A_t N_t^1. \tag{18}$$

These conditions imply that the bond market is cleared, i.e. $B_t^1 + B_t^2 + B_t^g = 0$ for all t. A key constraint is that nominal interest rates must be positive $i_t \geq 0$ at all dates t.

The conditions for an equilibrium (9)–(18) act as constraints on the planning problem we study next. However, in a spirit similar to Lucas and Stokey (1983), we seek to drop variables and constraints as follows. Given quantities, equations (13), (15) and (16) can be used to back out certain prices, wages and taxes. Since these variables do not affect welfare they can be dispensed with from our planning problem, along with all the equations except the market clearing condition (18), the borrowing constraint

$$C_2^2 \geq E_2^2 - \bar{B}_2, \tag{19}$$

and the requirement that nominal interest rates be positive

$$u'(C_t^1) = \beta(1 + i_t)u'(C_{t+1}^1) \qquad \text{with} \qquad i_t \geq 0. \tag{20}$$

We summarize these arguments in the following proposition.

Proposition 4 (Implementability)**.** *An allocation $\{C_t^i\}$ and $\{N_t^1\}$ together with nominal interest rates $\{E_t\}$ forms part of an equilibrium if and only if equations* (18), (19) *and* (20) *hold.*

Planning problem. We now solve the Ramsey problem of choosing the competitive equilibrium that maximizes social welfare, computed as a weighted average of agents utilities, with arbitrary Pareto weights λ^i . We only study configurations where it is optimal to put type-2 agents against their borrowing constraint in period 1 (which will always be the case for high enough values of E_2^2). We also only concern ourselves with the possibility that the zero lower bound might be binding in periods 1, and ignore that possibility in period 0 (which will always be the case for low enough values of E_0^2 and A_0).

We are led to the following planning problem

$$\max \sum_i \lambda^i \phi^i V^i \tag{21}$$

subject to

$$\sum_{i=1}^{2} \phi^i \frac{C_t^i}{A_t} = \phi^1 N_t^1 + E_t^2,$$

$$u'(C_1^1) = \beta(1+i_1)u'(C_2^1),$$

$$i_1 \geq 0,$$

$$C_2^2 = E_2^2 - \bar{B}_2.$$

The first-order conditions of this planning problem deliver a number of useful insights. First, we can derive a set of equations that characterize the labor wedge

$$\tau_t = 1 - \frac{v'(N_t^1)}{A_t u'(C_t^1)}$$

in every period t. This characterization involves the multiplier $\nu \leq 0$ on the constraint $u'(C_1^1) = \beta(1+i_1)u'(C_2^1)$. This multiplier ν is zero when the zero bound constraint $i_1 \geq 0$ is slack, and is negative otherwise. We have

$$\tau_0 \lambda^1 \phi^1 u'(C_0^1) = 0,$$

$$\tau_1 \lambda^1 \phi^1 \beta u'(C_1^1) - \nu u''(C_1^1) = 0,$$

$$\tau_2 \lambda^1 \phi^1 \beta^2 u'(C_2^1) + \nu \beta(1+i_1)u''(C_2^1) = 0.$$

Taken together, these equations imply that $\tau_0 = 0$, $\tau_1 \geq 0$ and $\tau_2 \leq 0$ with strict inequalities if the zero lower bound constraint binds. In other words, as long as the zero lower bound constraint doesn't bind, we achieve perfect macroeconomic stabilization. This ceases to be true when the zero lower bound binds. Then the economy is in a recession in period 1, in a boom in period 2, and is balanced in period 0. The zero lower bound precludes the reduction in nominal interest rates i_1 that would be required to stimulate the economy in period 1 by causing type-1 agents to reallocate consumption intertemporally, substituting away from period 2 and towards period 1. The boom in period 2 is designed to stimulate spending by type-1 agents through a wealth effect.

We can also derive a condition that shows that the borrowing of type-2 agents in period 0 should be restricted by the imposition of a binding borrowing constraint $B_1^2 \leq \bar{B}_1$. Indeed we have the following characterization of the relative ratios of intertemporal rates of susbstitution for agents of type 1 and 2:

$$\frac{1-\tau_1}{1+i_0} = \frac{\beta u'(C_1^2)}{u'(C_0^2)} \qquad \text{where} \qquad \frac{1}{1+i_0} = \frac{\beta u'(C_1^1)}{u'(C_0^1)}.$$

Here $\tau_1 \geq 0$ with a strict inequality if the zero lower bound constraint binds. In this case, the borrowing of type-2 agents in period 0 should be restricted by imposing a borrowing constraint on type-2 agents—or an equivalent tax on borrowing (subsidy on saving) so that the interest rate faced by type-2 agents is $(1+\tau_0^B)(1+i_0)$ where $\tau_0^B = \tau_1/(1-\tau_1)$. Doing so stimulates spending by type-1 agents in period 1, when the economy is in a recession. Intuitively, restricting borrowing by type-2 agents in period 0 reshuffles date-1 wealth away from type-1 agents with a low propensity to spend and towards type-2 agents with a high propensity to spend. The resulting increase in spending at date 1 helps stabilize the economy. And these stabilization benefits are not internalized by private agents—hence the need for government intervention.

We summarize these results in the following proposition.

Proposition 5. *Consider the planning problem (21). Then at the optimum, the labor wedges are such that $\tau_0 = 0$, $\tau_1 \geq 0$ and $\tau_2 \leq 0$ with strict inequalities if the zero lower bound constraint binds in period 1. When it is the case, it is optimal to impose a binding borrowing $B_1^2 \leq \bar{B}_1$ constraint on type-2 agents in period 0. The equivalent implicit tax on borrowing is given by $\tau_0^B = \tau_1/(1-\tau_1)$.*

When the zero lower bound constraint binds, the planning problem (21) can be seen as a particular case of the one studied in Section 2. The mapping is as follows. There are two states. The first state corresponds to period 0, and the second state to periods 1 and 2. In the first state, the commodities are the different varieties of the consumption good and labor in period 0. In the second state, the commodities are the different varieties of the consumption good and labor in periods 1 and 2. The constraint on prices is that the price of each variety must be the same in all periods. The zero lower bound constraint is captured in this formulation by the requirement that the (real) relative price of the same variety in periods 1 and 2 must be equal to one. Proposition 5 can then be seen as an application of Proposition 2.

3.2 International Liquidity Traps and Sudden Stops

In this section, we consider a small open economy subject to a liquidity trap induced by a sudden stop. There are three periods. Domestic agents consume both traded and non-traded goods, and the price of non-traded goods is sticky. The sudden stop is modeled as a borrowing constraint in the intermediate period. It can push the economy into a liquidity trap. We show that it is optimal to restrict the amount of domestic borrowing in the initial period through the imposition of a borrowing constraint or via capital controls.

Households. There is a representative domestic agent with preferences over non-traded goods, traded goods and labor given by the expected utility

$$\sum_{t=0}^{2} \beta^t U(C_{NT,t}, C_{T,t}, N_t).$$

Below we make some further assumptions on preferences.

Households are subject to the following budget constraints

$$P_{NT}C_{NT,t} + E_t P^*_{T,t} C_{T,t} + \frac{1}{1+i^*_t}\frac{1}{E_{t+1}} B_{t+1} \leq W_t N_t + E_t P^*_{T,t} \bar{E}_{T,t} + \Pi_t - T_t + \frac{1}{E_t} B_t, \tag{22}$$

where we impose $B_3 = 0$. Here P_{NT} is the price of non-traded goods which as we will see shortly, does not depend on t due to the assumed price stickiness; E_t is the nominal exchange rate, $P^*_{T,t}$ is the foreign currency price of the traded good, $E_t P^*_{T,t}$ is the domestic currency price of traded goods in period t; W_t is the nominal wage in period t; $\bar{E}_{T,t}$ is the endowment of traded goods in period t; Π_t represents aggregate profits in period t; T_t is a lump sum tax (that balances the government budget); B_t is short-term bond holdings in the foreign currency; and i^*_t is the foreign nominal interest rate.

We assume that in period 1, households face a borrowing constraint of the form

$$B_2 \leq P^*_{T,2} \bar{B}_2 \tag{23}$$

where $\bar{B}_2 < \bar{E}_{T,2}$.

Although there is no borrowing constraint in period 0 inherent to the environment, we consider prudential policy interventions that limit borrowing in the initial period. Thus, we suppose that the government selects a maximum debt level $\bar{B}_1$ and imposes

$$B_1 \leq P^*_{T,1} \bar{B}_1. \tag{24}$$

This inequality captures regulations that affect the inflow of capital into the country in the initial period.[5][6]

[5] We could have also imposed a lower bound on debt, but this will not be relevant in the cases that we are interested in. The borrowing constraint effectively allows us to control the equilibrium level of debt B_1.

[6] An alternative formulation that leads to the same results is to use a tax instrument (capital controls in

The households' first order conditions can be written as

$$\frac{E_t}{E_{t+1}}\frac{1}{1+i_t^*} \geq \frac{\beta U_{C_T,t+1}}{U_{C_T,t}}, \tag{25}$$

with equality if the borrowing constraint in period t is slack,

$$\frac{U_{C_T,t}}{E_t P_{T,t}^*} = \frac{U_{C_{NT},t}}{P_{NT}}, \tag{26}$$

and

$$\frac{W_t}{P_{NT}} = \frac{-U_{N,t}}{U_{C_{NT},t}}. \tag{27}$$

Firms. The traded goods are traded competitively in international markets. The domestic agents have an endowment $\bar{E}_t$ of these traded goods.

Non-traded goods are produced in each country by competitive firms that combine a continuum of non-traded varieties indexed by $j \in [0,1]$ using the constant returns to scale CES technology

$$Y_{NT,t} = \left(\int_0^1 Y_{NT,t}(j)^{1-\frac{1}{\epsilon}} dj\right)^{\frac{1}{1-\frac{1}{\epsilon}}},$$

with elasticity $\epsilon > 1$.

Each variety is produced by a monopolist using a linear technology:

$$Y_{NT,t}(j) = A_t N_t(j).$$

Each monopolist hires labor in a competitive market with wage W_t, but pays $W_t(1+\tau_L)$ net of a tax on labor. Monopolists must set prices once and for all in period 0 and cannot change them afterwards. The demand for each variety is given by $C_{NT,t}(P_{NT}(j)/P_{NT})^{-\epsilon}$ where $P_{NT}(j) = (\int (P_{NT}(j))^{1-\epsilon} dj)^{1/(1-\epsilon)}$ is the price of non traded goods. We assume that each firm j is owned by a household who sets the price $P_{NT}(j)$ in addition to making its consumption and labor supply decisions.[7] The corresponding price setting conditions

the form of a tax on capital inflows / subsidy on capital outflows) to increase the interest rate faced by domestic agents in period 0.

[7]The reason for this assumption is a form of market incompleteness due to the presence of borrowing constraints.

are symmetric across j and given by

$$P_{NT} = (1+\tau_L)\frac{\epsilon}{\epsilon-1}\frac{\sum_{t=0}^{2}\frac{\beta^t U_{C_T,t}}{P_{T,t}}\frac{W_t}{A_t}C_{NT,t}}{\sum_{t=0}^{2}\frac{\beta U^t_{C_T,t}}{P_{T,t}}C_{NT,t}}. \tag{28}$$

Government. The government sets the tax on labor τ_L, the borrowing limit $\bar{B}_1$ in period 0, and the nominal interest rate i_t which determines the exchange rate E_t in every period through the no arbitrage Uncovered Interest Parity (UIP) condition

$$1+i_t = (1+i_t^*)\frac{E_{t+1}}{E_t}. \tag{29}$$

In addition, it levies lump sum taxes T_t in period t to balance its budget

$$T_t + \tau_L W_t N_t = 0. \tag{30}$$

Equilibrium. An equilibrium takes as given the price of traded goods $P^*_{T,t}$ and the foreign nominal interest rate $\{i_t^*\}$. It specifies consumption of traded and non-traded goods $\{C_{T,t}, C_{NT,t}\}$, labor supply $\{N_t\}$, bond holdings $\{B_t\}$, the price of non-traded goods P_{NT}, wages $\{W_t\}$, nominal interest rates $\{i_t\}$ and exchange rates $\{E_t\}$, the borrowing limit $\bar{B}_1$, the labor taxes τ_L such that households and firms maximize, the government's budget constraint is satisfied, and markets clear:

$$C_{NT,t} = A_t N_t. \tag{31}$$

These conditions imply that the market for traded goods clears. A key constraint is that nominal interest rates must be positive $i_t \geq 0$ at all dates t.

The conditions for an equilibrium (22)–(31) act as constraints on the planning problem we study next. However, exactly as in Section 3.1 we can drop variables and constraints. Given quantities, equations (25), (27) and (28) can be used to back out certain prices, wages and taxes. Since these variables do not affect welfare they can be dispensed with from our planning problem, along with all the equations except the condition that determines agents' relative consumption of traded and non traded goods (26), the market clearing condition (31), the country budget constraint for traded goods

$$P^*_{T,0}\left[C_{T,0}-\bar{E}_0\right] + \frac{1}{1+i_0^*}P^*_{T,1}\left[C_{T,1}-\bar{E}_1\right] + \frac{1}{1+i_0^*}\frac{1}{1+i_1^*}\left[C_{T,2}-\bar{E}_2\right] \leq 0 \tag{32}$$

and the borrowing constraint

$$C_{T,2} \geq \bar{E}_2 - \bar{B}_2. \tag{33}$$

and the requirement that nominal interest rates be positive

$$1 + i_t = (1 + i_t^*)\frac{E_{t+1}}{E_t} \qquad \text{with} \qquad i_t \geq 0. \tag{34}$$

We summarize these arguments in the following proposition.

Proposition 6 (Implementability)**.** *An allocation $\{C_{T,t}, C_{NT,t}\}$ and $\{N_t\}$ together with prices for non-traded goods $\{P_{NT}\}$, nominal interest rates $\{i_t\}$ and exchange rates $\{E_t\}$ forms part of an equilibrium if and only if equations* (26)*,* (31)*,* (32)*,* (33) *and* (34) *hold.*

Homothetic Preferences. Next, we characterize the key condition (26) further by making some weak assumptions on preferences. We make two assumptions on preferences: (i) preferences over consumption goods are weakly separable from labor; and (ii) preferences over consumption goods are homothetic. These assumptions imply that

$$C_{NT,t} = \alpha(\frac{E_t P_{T,t}^*}{P_{NT,t}})C_{T,t},$$

for some function α that is increasing and differentiable. This conveniently encapsulates the restriction implied by the first order condition (26).

Define the indirect utility function, which encodes utility in period t when the consumption of traded goods is $C_{T,t}$ and the relative price of traded vs. non-traded goods is $p_t = \frac{E_t P_{T,t}^*}{P_{NT,t}}$ as

$$V(C_{T,t}, p_t) = U\left(\alpha(p_t)C_{T,t}, C_{T,t}, \frac{\alpha(p_t)}{A_t}C_{T,t}\right).$$

The derivatives of the indirect utility function will prove useful for our analysis. To describe these derivatives, it is useful to first introduce the labor wedge

$$\tau_t = 1 + \frac{1}{A_t}\frac{U_{N,t}}{U_{C_{NT},t}}.$$

The following proposition is borrowed from Farhi and Werning (2012b).

Proposition 7. *The derivatives of the value function are*

$$V_p(C_{T,t}, p_t) = \frac{\alpha_{p,t}}{p_t} C_{T,t} U_{C_{T},t}\, \tau_t,$$
$$V_{C_T}(C_{T,t}, p_t) = U_{C_{T},t} \left(1 + \frac{\alpha_t}{p_t} \tau_t\right).$$

These observations about the derivatives and their connection to the labor wedge will be key to our results. A private agent values traded goods according to its marginal utility $U_{C_T,t}$, but the actual marginal value in equilibrium is $V_{C_T,t}$. The wedge between the two equals $\frac{\alpha_t}{p_t}\tau_t = \frac{P_{NT}C_{NT,t}}{P_{T,t}C_{T,t}}\tau_t$, the labor wedge weighted by the relative expenditure share of non-traded goods relative to traded goods. We will sometimes refer to it as the *weighted labor wedge* for short.

In particular, a private agent undervalues traded goods $V_{C_T,t} > U_{C_T,t}$ whenever the economy is experiencing a recession, in the sense of having a positive labor wedge $\tau_t > 0$. Conversely, private agents overvalue traded goods $V_{C_T,t} < U_{C_T,t}$ whenever the economy is booming, in the sense of having a negative labor wedge $\tau_t < 0$. These effects are magnified when the economy is relatively closed, so that the relative expenditure share of non-traded goods is large.

Planning problem. We now solve the Ramsey problem of choosing the competitive equilibrium that maximizes the utility of domestic agents. We only study configurations where it is optimal to put domestic agents against their borrowing constraint in period 1 (which will always be the case for high enough values of $\bar{E}_2$). We also only concern ourselves with the possibility that the zero lower bound might be binding in periods 1, and ignore that possibility in period 0 (which will always be the case for low enough values of A_0).

We have the following planning problem

$$\max \sum_{t=0}^{2} \beta^t V(C_{T,t}, \frac{E_t P^*_{T,t}}{P_{NT}}) \tag{35}$$

subject to

$$(1 + i^*_1) E_2 \geq E_1,$$
$$P^*_{T,0}\left[C_{T,0} - \bar{E}_0\right] + \frac{1}{1+i^*_0} P^*_{T,1}\left[C_{T,1} - \bar{E}_1\right] = \frac{1}{1+i^*_0}\frac{1}{1+i^*_1}\bar{B}_2,$$
$$C_{T,2} = \bar{E}_2 - \bar{B}_2,$$

where the second and third constraints are the country budget constraint and the borrowing constraint. The first constraint is the zero lower bound constraint. It builds on the UIP condition $(1+i_1^*)E_2 = (1+i_1)E_1$ and captures the requirement that the domestic nominal interest rate i_1 be positive period 1. It is the key constraint that hampers macroeconomic stability. If the domestic nominal interest rate i_1 could be negative, then the exchange rates E_1 and E_2 would become free variables. The zero lower bound constraint puts a lower bound on the rate of the depreciation E_2/E_1 of the domestic currency, which can conflict with macroeconomic stability.

We have

$$V_{p,0} = 0,$$

$$\beta V_{p,1} \frac{P_{T,1}^*}{P_{NT}} = \nu,$$

$$\beta^2 V_{p,2} \frac{P_{T,2}^*}{P_{NT}} = -\nu(1+i_1^*),$$

where $\nu \geq 0$ is the multiplier on the zero lower bound constraint (the first constraint). Taken together, these equations imply that $\tau_0 = 0$, $\tau_1 \geq 0$ and $\tau_2 \leq 0$ with strict inequalities if the zero lower bound constraint binds. In other words, as long as the zero lower bound constraint doesn't bind, we achieve perfect macroeconomic stabilization. This ceases to be true when the zero lower bound binds. Then the economy is in a recession in period 1, in a boom in period 2, and is balanced in period 0. The zero lower bound precludes the reduction in nominal interest rates i_1 that would be required to depreciate the value of the period-1 exchange rate and stimulate the economy in period 1 by causing domestic agents to reallocate consumption intertemporally from period 2 to period 1, and intratemporally from traded goods to non-traded goods. A depreciation of the exchange rate in period 2 allows for a more depreciated exchange rate in period 1, but causes a boom in period 2.

We can also derive a condition that shows that the borrowing of domestic agents in period 0 should be restricted by the imposition of a binding borrowing constraint $B_1 \leq \bar{B}_1$. Indeed we have the following characterization

$$\frac{\beta(1+i_0^*)\frac{P_{T,0}^*}{P_{T,1}^*} V_{C_T,1}}{V_{C_T,0}} = 1,$$

or equivalently

$$\frac{\beta(1+i_0^*)\frac{P^*_{T,0}}{P^*_{T,1}}U_{C_T,1}\left(1+\frac{\alpha_1}{p_1}\tau_1\right)}{U_{C_T,0}\left(1+\frac{\alpha_0}{p_0}\tau_0\right)}=1,$$

Here $\tau_0 = 0$ and $\tau_1 \geq 0$ with a strict inequality if the zero lower bound constraint binds. In this case, the borrowing of domestic agents in period 0 should be restricted by imposing a borrowing constraint—or an equivalent tax on capital inflows / subsidy on capital outflows so that the interest rate faced by domestic agents is $(1+\tau_0^B)(1+i_0)$ where $\tau_0^B = \frac{\alpha_1}{p_1}\tau_1$. Doing so stimulates spending on non-traded goods by domestic agents in period 1, when the economy is in a recession. These stabilization benefits are not internalized by private agents—hence the need for government intervention.

We summarize these results in the following proposition.

Proposition 8. *Consider the planning problem* (35)*. Then at the optimum, the labor wedges are such that* $\tau_0 = 0$*,* $\tau_1 \geq 0$ *and* $\tau_2 \leq 0$ *with strict inequalities if the zero lower bound constraint binds in period 1. When it is the case, it is optimal to impose a binding borrowing* $B_1 \leq \bar{B}_1$ *constraint on domestic agents in period 0. The equivalent implicit tax on capital inflows / subsidy on capital outflows is given by* $\tau_0^B = \frac{\alpha_1}{p_1}\tau_1$*.*

When the zero lower bound constraint binds, the planning problem (35) can be seen as a particular case of the one studied in Section 2. The mapping is as follows. There are two states. The first state corresponds to period 0, and the second state to periods 1 and 2. In the first state, the commodities are the different varieties of the non-traded good, the traded good and labor in period 0. In the second state, the commodities are the different varieties of the non-traded good, the traded good and labor in periods 1 and 2. The possibility of trading the traded good intertemporally at given international prices is modeled as part of the technological constraint. The constraint on prices is that the price of each variety of non-traded good must be the same in all periods (in the domestic numeraire), and the requirement that price of the traded good $P_{T,t} = E_t P^*_{T,t}$ (in the domestic numeraire) must grow at rate $\frac{1}{1+i_1^*}\frac{P^*_{T,2}}{P^*_{T,1}}$ between periods 1 and 2. This last constraint derives from the zero lower bound constraint. So does the requirement that the (real) relative price of the same variety in periods 1 and 2 must be equal to one. Proposition 8 can then be seen as an application of Proposition 2.

3.3 Capital Controls with Fixed Exchange Rates

In Section 3.2, the domestic economy has a flexible exchange rate but faces a zero lower bound constraint. In this section, we use a similar model to focus on another constraint on macroeconomic stabilization in environments with nominal rigidities: a fixed exchange rate $E_t = E$. We consider a two period model of a small open economy that either chooses to fix its exchange rate vis a vis that of the foreign economy, or has lost this potential margin of adjustment because it is part of a currency union. Therefore the domestic economy loses all monetary autonomy: the domestic nominal interest rate must be equal to the foreign interest rate $i_t = i_t^*$. We show that this creates a role for capital controls to regain monetary autonomy. We refer the reader to Farhi and Werning (2012a) for a full-fledged analysis of capital controls with fixed exchange rates.

Households. There are two periods $t \in \{0, 1\}$. There is a representative domestic agent with preferences over non-traded goods, traded goods and labor given by the expected utility

$$\sum_{t=0}^{1} \beta^t U(C_{NT,t}, C_{T,t}, N_t).$$

Below we make some further assumptions on preferences.

Households are subject to the following budget constraints

$$P_{NT} C_{NT,t} + EP_{T,t}^* C_{T,t} + \frac{1}{(1+i_t^*)(1+\tau_t^B)} \frac{1}{E} B_{t+1} \leq W_t N_t + EP_{T,t}^* \bar{E}_{T,t} + \Pi_t - T_t + \frac{1}{E} B_t, \quad (36)$$

where we impose $B_2 = 0$. Here P_{NT} is the price of non-traded goods which as we will see shortly, does not depend on t due to the assumed price stickiness; E is the nominal exchange rate, $P_{T,t}^*$ is the foreign currency price of the traded good, $EP_{T,t}^*$ is the domestic currency price of traded goods in period t; W_t is the nominal wage in period t; $\bar{E}_{T,t}$ is the endowment of traded goods in period t; Π_t represents aggregate profits in period t; T_t is a lump sum tax (that balances the government budget); B_t is short-term bond holdings in the foreign currency; i_t^* is the foreign nominal interest rate and τ_t^B is the capital control tax (a tax on capital inflows / subsidy on capital outflows) which introduces a wedge between the domestic nominal interest rate $i_t = (1+i_t^*)(1+\tau_t^B) - 1$ and the foreign nominal interest rate i_t^*.

The households' first order conditions can be written as

$$\frac{1}{(1+i_t^*)(1+\tau_t^B)} = \frac{\beta U_{C_T,t+1}}{U_{C_T,t}}, \quad (37)$$

$$\frac{U_{C_T,t}}{EP_{T,t}^*} = \frac{U_{C_{NT},t}}{P_{NT}}, \quad (38)$$

and

$$\frac{W_t}{P_{NT}} = \frac{-U_{N,t}}{U_{C_{NT},t}}. \tag{39}$$

Firms. Firms are modeled exactly as in Section 3.2. The traded goods are traded competitively in international markets. The domestic agents have an endowment $\bar{E}_t$ of these traded goods. Non-traded goods are produced in each country by competitive firms that combine a continuum of non-traded varieties indexed by using a constant returns to scale CES technology with elasticity of substitution ϵ. Each variety is produced from labor by a monopolist using a linear technology with productivity A_t.

Each monopolist hires labor in a competitive market with wage W_t, but pays $W_t(1 + \tau_L)$ net of a tax on labor. Monopolists must set prices once and for all in period 0 and cannot change them afterwards. The associated price setting conditions are symmetric across firms and given by

$$P_{NT} = (1+\tau_L)\frac{\epsilon}{\epsilon-1}\frac{\sum_{t=0}^{1}\prod_{s=0}^{t-1}\frac{1}{(1+i_s^*)(1+\tau_s^B)}\frac{W_t}{A_t}C_{NT,t}}{\sum_{t=0}^{1}\prod_{s=0}^{t-1}\frac{1}{(1+i_s^*)(1+\tau_s^B)}C_{NT,t}}. \tag{40}$$

Government. The government sets the tax on labor τ_L, capital controls τ_t^B, and in addition, it levies lump sum taxes T_t in period t to balance its budget

$$T_t + \tau_L W_t N_t - \frac{\tau_t^B}{1+\tau_t^B}B_t = 0. \tag{41}$$

Equilibrium. An equilibrium takes as given the price of traded goods $P_{T,t}^*$, the foreign nominal interest rate $\{i_t^*\}$ and the exchange rate E. It specifies consumption of traded and non-traded goods $\{C_{T,t}, C_{NT,t}\}$, labor supply $\{N_t\}$, bond holdings $\{B_t\}$, the price of non-traded goods P_{NT}, wages $\{W_t\}$, the labor taxes τ_L, capital controls $\{\tau_t^B\}$ such that households and firms maximize, the government's budget constraint is satisfied, and markets clear:

$$C_{NT,t} = A_t N_t. \tag{42}$$

These conditions imply that the market for traded goods clears.

The conditions for an equilibrium (36)–(42) act as constraints on the planning problem we study next. However, exactly as in Section 3.1 we can drop variables and constraints. Given quantities, equations (37), (39) and (40) can be used to back out certain prices, wages and taxes. Since these variables do not affect welfare they can be dispensed with from our planning problem, along with all the equations except the condition that determines agents' relative consumption of traded and non traded goods (38), the market clearing condition (42), and the country budget constraint for traded goods

$$P^*_{T,0}\left[C_{T,0}-\bar{E}_0\right]+\frac{1}{1+i^*_0}P^*_{T,1}\left[C_{T,1}-\bar{E}_1\right]\leq 0 \tag{43}$$

We summarize these arguments in the following proposition.

Proposition 9 (Implementability). *An allocation $\{C_{T,t}, C_{NT,t}\}$ and $\{N_t\}$ together with prices for non-traded goods $\{P_{NT}\}$ and capital controls $\{\tau^B_t\}$, forms part of an equilibrium if and only if equations (38), (42), (43) hold.*

As in Section 3.2, we assume that preferences over consumption goods are weakly separable from labor; and that preferences over consumption goods are homothetic.

Planning problem. We now solve the Ramsey problem of choosing the competitive equilibrium that maximizes the utility of domestic agents. We have the following planning problem

$$\max\sum_{t=0}^{2}\beta^t V(C_{T,t},\frac{EP^*_{T,t}}{P_{NT}}) \tag{44}$$

subject to

$$P^*_{T,0}\left[C_{T,0}-\bar{E}_0\right]+\frac{1}{1+i^*_0}P^*_{T,1}\left[C_{T,1}-\bar{E}_1\right]\leq 0.$$

We have

$$V_{p,0}\frac{EP^*_{T,0}}{P_{NT}}+\beta V_{p,1}\frac{EP^*_{T,1}}{P_{NT}}=0,$$

which can be rewritten using Proposition 7 as

$$\alpha_{p,0}C_{T,0}U_{C_T,0}\,\tau_0+\beta\alpha_{p,1}C_{T,1}U_{C_T,1}\,\tau_1=0,$$

where τ_t is the labor wedge in period t. Taken together, these equations imply that τ_0 and τ_1 are of opposite signs, so that if the economy is experiencing a recession in period 0, then it is experiencing a boom in period 1 and vice versa.

We can also derive a condition that characterizes the optimal capital controls. Indeed, we have

$$\frac{\beta(1+i^*_0)\frac{P^*_{T,0}}{P^*_{T,1}}V_{C_T,1}}{V_{C_T,0}}=1,$$

or equivalently

$$\frac{\beta(1+i_0^*)\frac{P^*_{T,0}}{P^*_{T,1}}U_{C_T,1}\left(1+\frac{\alpha_1}{p_1}\tau_1\right)}{U_{C_T,0}\left(1+\frac{\alpha_0}{p_0}\tau_0\right)}=1,$$

implying that capital controls should be given by

$$1+\tau_0^B=\frac{1+\frac{\alpha_1}{p_1}\tau_1}{1+\frac{\alpha_0}{p_0}\tau_0}.$$

Suppose for example that the economy is in a boom in period 0 ($\tau_0 < 0$) and a recession in period 1 ($\tau_1 > 0$). Then the optimal tax on capital inflows / subsidy on capital outflows is positive $\tau_0^B > 0$. Doing so reduces spending on non-traded goods by domestic agents in period 0, when the economy is in a boom, and increases it in period 1, when the economy is in a recession. These stabilization benefits are not internalized by private agents—hence the need for government intervention.

We summarize these results in the following proposition.

Proposition 10. *Consider the planning problem* (44). *Then at the optimum, the labor wedges are such that* τ_0 *and* τ_1 *are of opposite signs. The optimal tax on capital inflows / subsidy on capital outflows is given by*

$$1+\tau_0^B=\frac{1+\frac{\alpha_1}{p_1}\tau_1}{1+\frac{\alpha_0}{p_0}\tau_0}.$$

The planning problem (44) can be seen as a particular case of the one studied in Section 2. The mapping is as follows. There are two states. The first state corresponds to period 0, and the second state to period 1. In the first state, the commodities are the different varieties of the non-traded good, the traded good and labor in period 0. In the second state, the commodities are the different varieties of the non-traded good, the traded good and labor in period 2. The possibility of trading the traded good intertemporally at given international prices is modeled as part of the technological constraint. The constraint on prices is that the price of each variety of non-traded good must be the same in all periods (in the domestic numeraire), and the requirement that price of the traded good (in the domestic numeraire) be given by $P_{T,t} = EP^*_{T,t}$ in every period. Proposition 8 can then be seen as an application of Proposition 2.

3.4 Fiscal Unions

In Section 3.3, we showed that in a small open economy with a fixed exchange rate, it may be desirable to use capital controls to affect private saving and borrowing decisions. In this section, we consider the related issue of risk-sharing decisions. We consider a model similar to that in Section 3.3. There are two important differences. First, we consider an economy with two states of the world but only one period. Second, we assume that private markets for risk sharing across states are inexistent. We think this difference captures a realistic feature of the world: that financial markets offer better opportunities for shifting wealth over time than across states of the world. In this context, governments can improve risk-sharing by arranging for state-contingent transfers from and towards their foreign counterparts and passing them through to domestic agents using lump-sum taxes and rebates. Importantly, we show that with a fixed exchange rates, these transfers should go beyond replicating the complete-markets solution. This leads to a theory of fiscal unions with a special role for currency unions. We refer the reader to Farhi and Werning (2012b) for a full-fledged analysis.

Households and firms. There are two periods $s \in \{H, L\}$ with respective probabilities $\pi(s)$. Goods are modeled exactly as in Section 3.2. The traded goods are traded competitively in international markets. The domestic agents have an endowment $\bar{E}_s$ of these traded goods in each state s. Non-traded goods are produced in each country by competitive firms that combine a continuum of non-traded varieties indexed by using a constant returns to scale CES technology with elasticity of substitution ϵ. Each variety is produced from labor by a monopolist using a linear technology with productivity A_s. Each monopolist hires labor in a competitive market with wage W_s, but pays $W_s(1+\tau_L)$ net of a tax on labor. Monopolists must set prices once and for all before the realization of the state s and cannot change them afterwards. We split the representative agent into a continuum of households $j \in [0,1]$. Household j is assumed to own the firm of variety j.

Households j maximizes utility

$$\sum_{s \in \{H,L\}} U(C_{NT,s}, C_{T,s}, N_s)\pi_s.$$

by choosing $\{C_{T,s}, C_{NT,s}, N_s\}$ and the prices set by its own firm P^j_{NT}, taking aggregate prices and wages $\{P_{T,s}, P_{NT}, W_s\}$ and aggregate demand $\{\bar{C}_{NT,s}\}$ as given, subject to

$$P_{NT}C_{NT,s} + EP^*_{T,s}C_{T,s} \leq W_s N_s + EP^*_{T,s}\bar{E}_{T,s} + \Pi^j_s + T_s, \tag{45}$$

where

$$\Pi^j_s = \left(P^j_{NT} - \frac{1+\tau_L}{A_s}W_s\right)\bar{C}_{NT,s}\left(\frac{P^j_{NT}}{P_{NT}}\right)^{-\varepsilon},$$

are the profits of the firm producing variety j. The corresponding first-order conditions are symmetric across j and given by

$$\frac{U_{C_T,s}}{EP^*_{T,s}} = \frac{U_{C_{NT},s}}{P_{NT}}, \tag{46}$$

$$-\frac{U_{N,s}}{W_s} = \frac{U_{C_{NT},s}}{P_{NT}}, \tag{47}$$

and the price setting condition

$$P_{NT} = (1+\tau_L)\frac{\varepsilon}{\varepsilon-1}\frac{\sum_{s\in\{H,L\}}\frac{U_{C_T,s}}{P_{T,s}}\frac{W_s}{A_s}\bar{C}_{NT,s}\pi_s}{\sum_{s\in\{H,L\}}\frac{U_{C_T,s}}{P_{T,s}}\bar{C}_{NT,s}\pi_s}. \tag{48}$$

Of course, in equilibrium we impose the consistency condition that $\bar{C}_{NT,s} = C_{NT,s}$ for all s.

Government. The government budget constraint is

$$T_s = \tau_L W_s N_s + \hat{T}_s, \tag{49}$$

with

$$\sum \pi_s Q_s \hat{T}_s \leq 0, \tag{50}$$

where Q_s are the state prices encoding the terms at which the government can transfer wealth from one state to the other by trading with their foreign counterparts.

Equilibrium. We can now define an equilibrium with incomplete markets. An equilibrium specifies quantities $\{C_{T,s}, C_{NT,s}, N_s\}$, prices and wages $\{EP^*_{T,s}, P_{NT}, W_s\}$, taxes $\{\tau_L, T_s\}$ and international fiscal transfers $\{\hat{T}_s\}$ such that households and firms maximize, the government's budget constraint is satisfied, and markets clear

$$C_{NT,s} = A_s N_s. \tag{51}$$

More formally, the conditions for an equilibrium are given by (46), (47), (45), (48) with $\bar{C}_s = C_s$, (49), (50), and (51).

As in the complete markets implementation, we can drop variables and constraints as follows. Given quantities, equations (47) and (48) can be used to back out certain prices, wages and taxes. Since these variables do not enter the welfare function they can be dispensed with from our planning problem, along with equations (47), (45), (48), (49), (50) as long as we impose the country budget constraint

$$\sum_{s\in\{H,L\}} \pi_s Q_s E P^*_{T,s} C_{T,s} \leq \sum_{s\in\{H,L\}} \pi_s Q_s E P^*_{T,s} \bar{E}_s. \tag{52}$$

We summarize these arguments in the following proposition.

Proposition 11 (Implementability). *An allocation $\{C_{T,s}, C_{NT,s}, N_s\}$ together with prices $\{EP^*_{T,s}, P_{NT}\}$ form part of an equilibrium with incomplete markets if and only if equations (46), (51) and (52) hold.*

As in Section 3.2, we assume that preferences over consumption goods are weakly separable from labor; and that preferences over consumption goods are homothetic.

Planning problem. We now solve the Ramsey problem of choosing the competitive equilibrium that maximizes the utility of domestic agents. We have the following planning problem

$$\max \sum_{s\in\{H,L\}} \pi_s V\left(C_{T,s}, \frac{P_{T,s}}{P_{NT}}\right) \tag{53}$$

subject to

$$\sum_{s\in\{H,L\}} \pi_s Q_s E P^*_{T,s} C_{T,s} \leq \sum_{s\in\{H,L\}} \pi_s Q_s E P^*_{T,s} \bar{E}_s.$$

Using Proposition 7, we can transform the first order conditions as follows. First, we get a condition

$$\sum_{s\in\{H,L\}} \alpha_{p,s} C_{T,s} U_{C_T,0}\, \tau_0 = 0,$$

where τ_s is the labor wedge in state s. Taken together, these equations imply that τ_H and τ_L are of opposite signs, so that if the economy is experiencing a recession in state L, then it is experiencing a boom in state H and vice versa.

We can also derive a condition that characterizes the optimal capital controls. Indeed, we have

$$\frac{Q_L P^*_{T,L}}{Q_H P^*_{T,H}} \frac{V_{C_T,H}}{V_{C_T,L}} = 1,$$

or equivalently

$$\frac{Q_L P^*_{T,L}}{Q_H P^*_{T,H}} \frac{U_{C_T,H}\left(1 + \frac{\alpha_H}{p_H}\tau_H\right)}{U_{C_T,L}\left(1 + \frac{\alpha_L}{p_L}\tau_L\right)} = 1.$$

International transfers are then simply given by $\hat{T}_s = P_{T,s}(C_{T,s} - \bar{E}_{T,s})$. Suppose for example that the economy is in a boom in state H ($\tau_H < 0$) and a recession in state L ($\tau_L > 0$). Then international fiscal transfers from foreign should be tilted towards state L. Doing so reduces spending on non-traded goods by domestic agents in state H, when the economy is in a boom, and increases it in state L, when the economy is in a recession. These stabilization benefits are not internalized by private agents—hence the need for the government to go beyond replicating the complete markets solution (if agents had access to complete markets to share risk with state prices Q_s in state s), which would entail

$$\frac{Q_L P^*_{T,L}}{Q_H P^*_{T,H}} \frac{U_{C_T,H}}{U_{C_T,L}} = 1.$$

Indeed, there exists an alternative implementation where agents have access to complete markets but states prices $\frac{Q_s}{1+\tau_s^D}$ are distorted by portfolio taxes

$$\tau_s^D = \frac{\alpha_s}{p_s} \tau_s.$$

We summarize these results in the following proposition.

Proposition 12. *Consider the planning problem (53). Then at the optimum, the labor wedges are such that τ_H and τ_L are of opposite signs. International fiscal transfers impose implicit portfolio taxes given by*

$$\tau_s^D = \frac{\alpha_s}{p_s} \tau_s.$$

The planning problem (53) can be seen as a particular case of the one studied in Section 2. The mapping is as follows. There are two states. The first state corresponds to state L, and the second state to state H. In the first state, the commodities are the different varieties of the non-traded good, the traded good and labor in state L. In the second state, the commodities are the different varieties of the non-traded good, the traded good and labor in state H. The possibility of trading the traded good intertemporally at given international prices is modeled as part of the technological constraint. The constraint on prices is that the price of each variety of non-traded good must be the same in all periods (in the domestic numeraire), and the requirement that price of the traded good (in the domestic numeraire) be given by $P_{T,t} = EP^*_{T,t}$ in every period. Proposition 8 can then be seen as an application of Proposition 2.

A Appendix

A.1 Proof of Proposition 1

We use

$$\sum_{j\in J_s} P_{j,s} X^i_{I,j,s} = 1,$$

to get for any λ_s

$$\lambda^i V^i_{I,s} = \left[\sum_{j\in J_s} \left(\mu F_{j,s} - \lambda_s P_{j,s} \right) X^i_{I,j,s} + \lambda_s \right],$$

and in particular for $\lambda_s = \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}}$, we get

$$\lambda^i V^i_{I,s} = \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} \left[\sum_{j\in J_s} \left(P_{j^*(s),s} \frac{\mu F_{j,s}}{\mu F_{j^*(s),s}} - P_{j,s} \right) X^i_{I,j,s} + 1 \right].$$

We can re-express this as

$$\lambda^i V^i_{I,s} = \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} \left[1 - \sum_{j\in J_s} \frac{P_{j,s} X^i_{j,s}}{I^i_s} \frac{I^i_s X^i_{I,j,s}}{X^i_{j,s}} \tau_{j,s} \right].$$

We use

$$V^i_{P_k,s} = -X^i_{k,s} V^i_{I,s},$$

$$S^i_{k,j,s} = X^i_{P_k,j,s} + X^i_{k,s} X^i_{I,j,s},$$

$$\sum_{j\in J_s} P_{j,s} X^i_{P_k,j,s} + X^i_{k,s} = 0,$$

$$\sum_{j\in J_s} P_{j,s} X^i_{I,j,s} = 1,$$

to get

$$-\nu \cdot \Gamma_{k,s} = \sum_{i\in I} \sum_{j\in J_s} \mu F_{j,s} \left[X^i_{P_k,j,s} + X^i_{k,s} X^i_{I,j,s} \right],$$

$$-\nu \cdot \Gamma_{k,s} = \sum_{i\in I} \sum_{j\in J_s} \left(\mu F_{j,s} - \lambda_s P_{j,s} \right) \left[X^i_{P_k,j,s} + X^i_{k,s} X^i_{I,j,s} \right] - \sum_{i\in I} \lambda_s X^i_{k,s} + \sum_{i\in I} \sum_{j\in J_s} \lambda_s P_{j,s} X^i_{k,s} X^i_{I,j,s},$$

$$- \nu \cdot \Gamma_{k,s} = \sum_{i \in I} \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} \sum_{j \in J_s} \left(P_{j^*(s),s} \frac{\mu F_{j,s}}{\mu F_{0,s}} - P_{j,s} \right) \left[X^i_{P_{k},j,s} + X^i_{k,s} X^i_{I,j,s} \right]$$

$$- \sum_{i \in I} \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} X^i_{k,s} + \sum_{i \in I} \sum_{j \in J_s} \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} P_{j,s} X^i_{k,s} X^i_{I,j,s},$$

and finally

$$-\nu \cdot \Gamma_{k,s} = - \sum_{i \in I} \frac{F_{j^*(s),s}}{P_{j^*(s),s}} \sum_{j \in J_s} P_{j,s} \tau_{j,s} S^i_{k,j,s}.$$

Summing up, we have

$$\lambda^i V^i_{I,s} = \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} \left[1 - \sum_{j \in J_s} \frac{P_{j,s} X^i_{j,s}}{I^i_s} \frac{I^i_s X^i_{I,j,s}}{X^i_{j,s}} \tau_{j,s} \right],$$

$$\nu \cdot \Gamma_{k,s} = \sum_{i \in I} \frac{\mu F_{j^*(s),s}}{P_{j^*(s),s}} \sum_{j \in J_s} P_{j,s} \tau_{j,s} S^i_{k,j,s}.$$

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