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# Optimal Cooperative Taxation in the Global Economy

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## Optimal Cooperative Taxation in the Global Economy\*

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### ABSTRACT

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How should countries cooperate in setting fiscal and trade policies when government expenditures must be financed with distorting taxes? We show that even if countries cannot make explicit transfers to each other, every point on the Pareto frontier is production efficient, so that international trade and capital flows should be effectively free. Trade agreements must be supplemented with fiscal policy agreements. Residence-based income tax systems have advantages over source-based systems. Taxing all household asset income at a country-specific uniform rate and setting the corporate income tax to zero yield efficient outcomes. Value-added taxes should be adjusted at the border.

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# I Introduction

In the face of increased globalization, the design of the international tax system is a pressing concern for policy makers. The European Union, for example, has conducted extensive discussions on the feasibility and desirability of tax harmonization and has also discussed the possibility of forming a fiscal union. Awareness of how fiscal policy can be used to mimic tariffs is increasing. Recent discussion on the tax reform package in the United States – see, for example, Auerbach et al. (2017) – focused on the extent to which border adjustments were being proposed to mimic tariffs.

In this paper, we develop a dynamic international trade model and use it to ask how countries should cooperate on fiscal and trade policy when government expenditures must be financed with distorting taxes. We show that production efficiency is optimal so that goods, services, and capital should effectively flow freely across borders. We argue that residence-based income tax systems have advantages over source-based systems and that value-added taxes should be adjusted at the border. We show that the choice of tax system determines whether taxes on domestic activities can act as tariffs on international trade and thereby undermine international agreements on free trade. Thus, if trade agreements are to be effective, they must be supplemented by agreements on fiscal policy. We argue that integrating dynamic public finance with dynamic international trade provides insights that are often not obvious in static formulations.

Our dynamic trade model is based on Backus, Kehoe, and Kydland (1994), though as we argue, the results hold in a variety of other trade models. We use both the Ramsey and the Mirrlees approaches to optimal taxation. In the Ramsey approach, the tax system is exogenously given, while in the Mirrlees approach, the tax system is restricted only by informational constraints. In both cases, we study cooperative equilibria.

The bulk of our analysis is conducted using the Ramsey approach. We begin with a benchmark system that taxes consumption, labor income, and international trade and does not allow for direct transfers across governments. We show that every point on the Pareto frontier has production efficiency as long as countries are connected by direct or indirect trade links. We show that any such point can be implemented by setting trade taxes so that import tariffs are exactly offset by export subsidies and appropriately setting consumption

and labor income taxes. We also show that wedges between marginal rates of substitution and marginal rates of transformation are not necessarily equated across countries, so that tax rates across countries need not be equal. In this sense, we show that tax harmonization is not necessarily optimal.

We extend the tax system to allow for lump-sum transfers across governments and show that the Ramsey outcomes can be implemented by setting trade taxes to zero. This result shows that the role of offsetting trade taxes is solely to redistribute resources across countries. We show that there is a point on the Pareto frontier where government-to-government transfers are zero. This result implies that if countries have chosen an allocation associated with this point, then even if they are prevented from making direct or indirect transfers to each other, no Pareto improvement is possible.

Adding to the benchmark system other widely used taxes, such as taxes on corporate income and returns to household assets, as well as value-added taxes, does not change the Pareto frontier. We also analyze alternative tax systems that exclude some of the taxes in our benchmark system. We do so because they are widely used, and because other taxes may be easier to administer.

We begin by considering a system that taxes only labor income, corporate income, and household asset income. It does not tax consumption or international trade but does allow for government-to-government transfers. We show that any point on the Pareto frontier with the benchmark system can be implemented by setting the corporate income tax to zero and appropriately choosing the other two taxes. We also show that non-zero corporate income taxation can act as a restriction on capital mobility. This result shows that free trade agreements need to be supplemented with agreements on fiscal policy.

We show that it is optimal to tax all types of inflation-adjusted household asset income – including interest, dividends and capital gains – at a common country-specific rate. We go on to show that tax systems that allow only labor and corporate income to be taxed cannot, in general, implement outcomes on the Pareto frontier. Since a uniform tax on household asset income is residence based, while a tax on corporate income is source based, our analysis implies that residence-based tax systems have advantages over source-based systems.

It is often argued that source-based systems – for example, those that use corporate

income taxes – have administrative advantages. While we have not explicitly modelled administrative ease, our analysis shows that source-based taxes can be used to implement the Ramsey allocation. We exploit the idea that while the Ramsey allocation uniquely pins down wedges, it can be implemented with a variety of different tax systems. Consider, for example, corporate income taxes. We show that the Ramsey allocation can be implemented with such taxes as long as the tax base is changed to exclude investment expenses and the taxes are constant either over time or across countries. Other taxes will in general need to be adjusted appropriately. These insights help clarify issues in the design of optimal corporate income tax systems (see, for example, OECD 2007).

Value-added taxes are also widely used as part of tax systems in many countries. We examine the role of border adjustments in setting these taxes. The tax base of a value-added tax with border adjustment, referred to as *VAT with BA*, excludes revenues from exports and includes expenditures on imports. Since such a tax is equivalent to a consumption tax, a system that includes this tax, together with a tax on labor income, can implement any point on the Pareto frontier. The tax base of a value-added tax without border adjustment (*VAT without BA*) includes revenues from exports and excludes expenditures on imports. We show that a system that has a VAT without BA and a labor income tax introduces intertemporal trade wedges if, in the benchmark system, optimal consumption tax rates vary over time. Thus, in general, a system with a VAT without BA and a labor income tax cannot implement outcomes on the Pareto frontier. Furthermore, with this tax system, since VATs can effectively impose tariffs, trade agreements that are not supplemented with fiscal policy agreements can be ineffective. Taken together, these findings suggest that systems that allow for border adjustments are desirable.

These results shed light on apparent differences between the literature in public finance (see Auerbach et al. 2017) and that in international trade (see Grossman 1980, Feldstein and Krugman 1990, and Costinot and Werning 2018) on the desirability of border adjustments. The public finance literature has argued that border adjustments are desirable, while the international trade literature has argued that they are irrelevant. The international trade literature effectively considers uniform tax systems in the sense that the VAT tax rate is the same for all goods. We can think of our dynamic economy as a static economy with an infinite

number of goods. If, in the benchmark system, optimal consumption tax rates are constant over time, then the associated VAT tax rate is the same for all goods so that, regardless of border adjustments, systems with VAT and labor income taxes can implement outcomes on the Pareto frontier. If, in the benchmark system, optimal consumption taxes vary over time, then the associated VAT rate is different for different goods, and the international trade results no longer apply. Our results help reconcile these differences and suggest that border adjustments are desirable in general. Barbiero et al. (2017) show that permanent changes in border adjustments are irrelevant if they are unanticipated, while they are not if anticipated. The difference between the two exercises is that the first change is uniform, while the second is not.

The analysis of border adjustments helps us compare destination-based with origin-based taxes on goods and services. A tax system is destination based if tax rates at the destination of use do not depend on the origin of production and is origin based if the tax rates do not depend on the destination of use. Value added taxes with border adjustment are destination based, and those without border adjustment are origin based. Thus, our results suggest that destination-based systems have advantages over origin-based systems.

Our result that the Ramsey equilibrium without transfers is production efficient differs from that in Keen and Wildasin (2004), who argue that such equilibria are, in general, production inefficient. The reason for this difference is that Keen and Wildasin impose restrictions on trade taxes. With their restrictions, it turns out that it may not be possible to simultaneously achieve production efficiency and the needed redistribution across countries. They require tariffs on each imported good to be the same, regardless of its origin of production. Likewise, export subsidies on a given good cannot depend on the destination of exports. In contrast, we explicitly allow trade taxes for each good to depend on the origin and the destination.

Restrictions on policies of the type in Keen and Wildasin are of very limited applied interest, since countries routinely impose different tariffs on the same physical good based on country of origin or destination. For example, groups of countries often enter into trade agreements with one another that impose different tariffs based on whether a given good is produced within or outside the group. In examining cooperative Ramsey equilibria, our view

is that the set of allowable tax instruments should include widely used tax instruments. From this perspective, it seems unreasonable to exclude instruments that countries routinely use. In any event, even if we were to impose restrictions of the kind in Keen and Wildasin, it turns out that they would not be generically binding in our dynamic model.

In our discussion of alternative implementations, we have assumed that explicit transfers, rather than offsetting trade taxes, are used to redistribute resources across countries. We have done so because even though these are equivalent, our view is that transfers have advantages over offsetting trade taxes. This view is based on two considerations. First, adopting a policy of explicitly free trade for a wide variety of goods and services helps protect policy makers from lobbying by self-interested groups seeking to promote their own sectors. Olson (2009) has persuasively argued that countries often adopt tariffs that hurt the vast majority of their citizens because tariffs on individual sectors confer concentrated benefits on small groups and diffuse costs on large groups (see also Grossman and Helpman, 1994). The large group may have a free rider problem in overcoming the lobbying efforts of a particular small group. The large group may, however, be able to overcome the interest of many small groups by negotiating a free trade agreement that applies to all sectors. One example of a cooperative agreement that combines internal free trade with transfers is the European Union.

Second, we think of transfers as consisting of more than explicit monetary transfers. Countries agree to treaties on a variety of issues such as the environment, military cooperation, migrant flows, and the like. The kinds of agreements countries arrive at on these issues are linked to the kinds of agreements they arrive at on trade issues.

Our model can be extended to address issues of fiscal federalism. In this extension, countries are reinterpreted as states or provinces, and the public good provided by each country in our model is interpreted as a local public good. We can easily allow for national public goods that are provided by the federal government and for labor mobility. We conjecture that as long as taxes can depend on the origin and destination of mobile agents, production efficiency is still optimal.

We go on to argue that our results generalize to other international trade models such as Obstfeld and Rogoff (1995), Stockman and Tesar (1995), and Eaton and Kortum (2002). Finally, we show that our results extend to a Mirrlees-like environment in which

the government can use nonlinear tax systems and the productivity of households is private information. We show that these outcomes also satisfy production efficiency so that free trade and unrestricted capital mobility are optimal.

For ease of exposition, we study a deterministic model. It is straightforward to extend the analysis to stochastic models in which productivity, government consumption, and other shocks generate fluctuations in the aggregates. All our results continue to hold in the stochastic model. In such models, optimal consumption tax rates will typically vary with the underlying state, even in the stochastic steady state. These fluctuations may be large if the underlying shocks are large. This observation strengthens the case for the desirability of household asset taxes over taxation of corporate income and for the desirability of border adjustments in VAT systems.

One purpose of this paper is to help integrate static trade theory into widely used dynamic macroeconomic models of public finance. Doing so provides insights that are often not obvious in static public finance formulations. We have clarified that while systems of taxation with and without border adjustment are equivalent in a class of static models, they are not equivalent in dynamic models. This clarification helps advance the discussion on the role of different ways of adjusting taxes at the border. Second, we have shown that dynamic models are useful in understanding the role that incentives play in the discussion of international asset income taxation. Third, the restrictions on policies that are binding in static models, as they are in Keen and Wildasin (2004), are not generically binding in dynamic extensions of those static models. Fourth, we can easily use the insights from the theory of repeated games - see our online Appendix F - to provide non-cooperative foundations for Pareto optimal outcomes. In this sense, cooperative Ramsey equilibria in a dynamic model are not merely benchmarks, but outcomes that can be attained even when countries cannot commit to cooperating. In contrast, in static models, cooperative outcomes typically cannot be attained in a non-cooperative setting.

## II A Dynamic Trade Economy

The model is that in Backus, Kehoe, and Kydland (1994), with distorting taxes. There are  $N$  countries indexed by  $i = 1, \dots, N$ . The preferences of a representative household in each



country are over consumption  $c_{it}$ , labor  $n_{it}$ , and government consumption,  $g_{it}$ ,

$$(1) \quad U^i = \sum_{t=0}^{\infty} \beta^t [u^i(c_{it}, n_{it}) + h^i(g_{it})].$$

We assume that  $u^i$  satisfies the usual properties and  $h^i$  is an increasing, concave, and differentiable function. We assume that the total endowment of time is normalized to be one. For much of what follows, we assume, without loss of generality, that government consumption is exogenously given.

Each country,  $i$ , produces a country-specific intermediate good,  $y_{it}$ , according to a production technology given by

$$(2) \quad \sum_{j=1}^N y_{ijt} = y_{it} = F^i(k_{it}, n_{it}),$$

where  $y_{ijt}$  denotes the quantity of intermediate goods produced in country  $i$  and used in country  $j$ ,  $k_{it}$  is the capital stock,  $n_{it}$  is labor input, and  $F^i$  is constant returns to scale. Here the first subscript denotes the location of production, and the second subscript denotes the location of use. The intermediate goods produced by each country are used to produce a country-specific final good that can be used for private consumption,  $c_{it}$ ; public consumption,  $g_{it}$ ; and investment,  $x_{it}$ , according to

$$(3) \quad c_{it} + g_{it} + x_{it} \leq G^i(y_{1it}, \dots, y_{Nit}),$$

where  $G^i$  is constant returns to scale. Capital accumulates according to the law of motion

$$(4) \quad x_{it} = k_{it+1} - (1 - \delta) k_{it},$$

so that the final goods resource constraint is

$$(5) \quad c_{it} + g_{it} + k_{it+1} - (1 - \delta) k_{it} \leq G^i(y_{1it}, \dots, y_{Nit}).$$

Note that in this economy, only intermediate goods are traded across countries; final

goods are not.

We use  $G_{j,t}^i$  to denote the derivative of the intermediate goods production function of country  $i$  with respect to intermediate good of country  $j$ , in period  $t$ , and  $u_{c,t}^i$  and  $u_{n,t}^i$  to denote the marginal utilities of consumption and labor in period  $t$ . We then have that if lump-sum taxes as well as government to government transfers are available, the allocations on the Pareto frontier satisfy the following efficiency conditions:

$$(6) \quad -\frac{u_{ct}^i}{u_{nt}^i} = \frac{1}{G_{i,t}^i F_{nt}^i},$$

$$(7) \quad \frac{u_{c,t}^i}{\beta u_{c,t+1}^i} = 1 - \delta + G_{i,t+1}^i F_{kt+1}^i;$$

and, for each pair of goods  $(j, l)$ ,

$$(8) \quad \frac{G_{j,t}^i}{G_{l,t}^i} \text{ is the same across countries } i;$$

and, for each good  $j$ ,

$$(9) \quad \frac{G_{j,t}^i}{G_{j,t+1}^i} [G_{i,t+1}^i F_{k,t+1}^i + 1 - \delta] \text{ is the same across countries } i.$$

These conditions, together with the resource constraints, characterize the Pareto frontier.

These conditions mean that there are no intratemporal wedges (condition (6)), no intertemporal wedges (condition (9)), and no production distortions (conditions (7) and (8)). We say that an allocation is *statically production efficient* if it satisfies (8), *dynamically production efficient* if it satisfies (9), and simply *production efficient* if it satisfies both. Static production efficiency requires that the marginal rate of technical substitution for any pair of intermediate goods be equated across countries. Dynamic production efficiency requires that capital be allocated so as to equate the social rate of return on capital across the different countries.

Note, for future use, that the conditions above also imply the intertemporal consump-

tion efficiency condition that, for all goods  $j$ ,

$$(10) \quad \frac{u_{c,t}^i}{\beta u_{c,t+1}^i} \frac{G_{j,t}^i}{G_{j,t+1}^i} \text{ is the same across countries } i.$$

### A. Equilibria with Consumption, Labor Income, and Trade Taxes

Consider now the economy with distorting taxes. Each government finances public consumption and initial debt with proportional taxes on consumption and labor income,  $\tau_{it}^c$  and  $\tau_{it}^n$ ; trade taxes; and a tax on initial wealth,  $\tau_i^W$ . The trade taxes consist of an export tax,  $\tau_{ijt}^x$ , levied on exports shipped from country  $i$  to country  $j$ , and a tariff,  $\tau_{ijt}^m$ , levied on imports shipped from country  $i$  to country  $j$ .

#### *Firms*

Each country has two representative firms. The *intermediate good firm* in each country uses the technology in (2) to produce the intermediate good using capital and labor, purchases investment goods, and accumulates capital according to (4). Let  $V_{i0}$  be the value of the firm in period zero after the dividend paid in that period,  $d_{i0}$ . The intermediate good firms maximize the value of dividends

$$(11) \quad V_{i0} + d_{i0} = \sum_{t=0}^{\infty} Q_t \left[ p_{iit} y_{iit} + \sum_{j \neq i} (1 - \tau_{ijt}^x) p_{ijt} y_{ijt} - w_{it} n_{it} - q_{it} x_{it} \right],$$

subject to (2) and (4). Here,  $p_{ijt}$  is the price of the intermediate good produced in country  $i$  and sold in country  $j$  at  $t$ ,  $w_{it}$  is the wage rate, and  $q_{it}$  is the price of the final good, all in units of a common world numeraire. The intertemporal price  $Q_t$  is the price of the numeraire at time  $t$  in units of the numeraire at zero ( $Q_0 = 1$ ). Note that we assume that the intertemporal prices  $Q_t$  are the same across countries. This assumption captures the idea that world capital markets are fully integrated. Below, we explore policies that restrict international capital flows.

The *final goods firm* of country  $i$  chooses the quantities of intermediate goods to

maximize the value of dividends:

$$\sum_{t=0}^{\infty} Q_t \left[ q_{it} G^i(y_{iit}, y_{jit}) - p_{iit} y_{iit} - \sum_{j \neq i} (1 + \tau_{jit}^m) p_{jit} y_{jit} \right].$$

For future use, note that if we define  $r_{t+1}^f$  to be the return on one-period bonds in units of the numeraire between period  $t$  and  $t + 1$ , then  $Q_t/Q_{t+1} = 1 + r_{t+1}^f$  for  $t \geq 0$ .

### **Households**

The household problem in country  $i$  is to maximize utility (1) subject to the budget constraint

$$(12) \quad \sum_{t=0}^{\infty} Q_t [(1 + \tau_{it}^c) q_{it} c_{it} - (1 - \tau_{it}^n) w_{it} n_{it}] \leq (1 - \tau_i^W) a_{i0},$$

with

$$a_{i0} = V_{i0} + d_{i0} + Q_{-1} b_{i0} + (1 + r_0^f) f_{i0},$$

where  $a_{i0}$  denotes net holdings of assets by the household of country  $i$ ;  $Q_{-1} b_{i0}$  denotes holdings of domestic public debt in units of the numeraire, inclusive of interest; and  $(1 + r_0^f) f_{i0}$  denotes holdings of claims on households in the other country, in units of the numeraire, also inclusive of interest. Without loss of generality, households within a country hold claims to the firms in that country as well as the public debt of its government. For most of our analysis, we assume that the initial net foreign asset position in real terms—namely,  $f_{i0}/q_{i0}$ —is fixed.

### **Governments**

The budget constraint of the government of country  $i$  is given by

$$(13) \quad \sum_{t=0}^{\infty} Q_t \left[ \tau_{it}^c q_{it} c_{it} + \tau_{it}^n w_{it} n_{it} + \sum_{j \neq i} \tau_{jit}^m p_{jit} y_{jit} + \sum_{j \neq i} \tau_{ijt}^x p_{ijt} y_{ijt} - q_{it} g_{it} \right] = Q_{-1} b_{i0} - \tau_i^W a_{i0}.$$

Combining the budget constraints of the government and the household (with equality) in each country, we obtain the balance of payments condition:

$$(14) \quad \sum_{t=0}^{\infty} Q_t \sum_{j \neq i} [p_{ijt} y_{ijt} - p_{jit} y_{jit}] = - \left(1 + r_0^f\right) f_{i,0},$$

for all  $i$ , and with  $\sum_i \left(1 + r_0^f\right) f_{i,0} = 0$  (see Appendix A for the derivation.<sup>1</sup>)

A *competitive equilibrium* consists of allocations  $\{c_{it}, n_{it}, y_{ijt}, k_{it+1}, x_{it}, g_{it}\}$ ; prices and initial dividends,  $\{q_{it}, p_{ijt}, w_{it}, Q_t, V_{i0}, d_{i0}\}$ ; and policies  $\{\tau_{it}^c, \tau_{it}^n, \tau_{ijt}^m, \tau_{ijt}^x\}$ ,  $\tau_i^W$ , given  $k_{i0}, Q_{-1} b_{i0}, \left(1 + r_0^f\right) f_{i,0}$ , such that firms maximize value; households maximize utility subject to their budget constraints; the governments' budget constraints hold; the balance of payments conditions (14) hold; and markets clear in that (2), (3), and (4) hold.

We say that an allocation  $\{c_{it}, n_{it}, y_{ijt}, k_{it+1}, x_{it}, g_{it}\}$  is *implementable* if it is part of a competitive equilibrium.

Next, we characterize the competitive equilibria. To do so, we rearrange the first-order conditions of households and firms to obtain (details are in Appendix A)

$$(15) \quad -\frac{u_{c,t}^i}{u_{n,t}^i} = \frac{(1 + \tau_{it}^c)}{(1 - \tau_{it}^n)} \frac{G_{i,t}^i F_{n,t}^i}{G_{i,t}^i F_{n,t}^i},$$

$$(16) \quad \frac{u_{c,t}^i}{\beta u_{c,t+1}^i} = \frac{(1 + \tau_{it}^c)}{(1 + \tau_{it+1}^c)} [G_{i,t+1}^i F_{k,t+1}^i + 1 - \delta];$$

for each pair of goods  $(j, l)$ ,

$$(17) \quad \frac{(1 - \tau_{jit}^x) (1 + \tau_{lit}^m) G_{j,t}^i}{(1 + \tau_{jit}^m) (1 - \tau_{lit}^x) G_{l,t}^i} \text{ is the same for all } i;$$

and, for each good  $j$ ,

$$(18) \quad \frac{(1 + \tau_{jit+1}^m) (1 - \tau_{jit}^x) G_{j,t}^i}{(1 - \tau_{jit+1}^x) (1 + \tau_{jit}^m) G_{j,t+1}^i} [G_{i,t+1}^i F_{k,t+1}^i + 1 - \delta] \text{ is the same for all } i.$$

Comparing these conditions with the ones for the Pareto frontier with lump-sum tax-

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<sup>1</sup>For future reference, all of the appendices are online.

ation – (6), (7), (8), and (9) – we have that the consumption and labor taxes create an intratemporal wedge, as can be seen in (15), and that time-varying consumption taxes create intertemporal wedges, as can be seen in (16). The consumption and labor income taxes do not affect the production efficiency conditions (17) and (18). We say that the economy has *no trade wedges* if the trade taxes are set so that (17) coincides with (8) and (18) coincides with (9). One example of such an economy sets trade taxes so that  $\tau_{jit}^m = -\tau_{jit}^x$ . In our proposition below, we will construct trade taxes with this property. If the economy has trade wedges, then trade taxes distort production efficiency.

We can also use (16) and (18) to write the intertemporal consumption condition

$$(19) \quad \frac{(1 + \tau_{jit+1}^m)(1 - \tau_{jit}^x)(1 + \tau_{it+1}^c)}{(1 - \tau_{jit+1}^x)(1 + \tau_{jit}^m)(1 + \tau_{it}^c)} \frac{G_{j,t}^i}{G_{j,t+1}^i} \frac{u_{c,t}^i}{\beta u_{c,t+1}^i} \text{ is the same for all } i,$$

which makes clear how time-varying ratios of consumption and trade taxes distort this intertemporal margin across households in different countries.

For future use, it is helpful to express the balance of payments condition in terms of the allocations and policies. Straightforward algebra (shown in Appendix A) yields that the balance of payments condition can be written as

$$(20) \quad \sum_{t=0}^{\infty} \frac{1}{\prod_{s=0}^t [G_{i,s}^i F_{k,s}^i + 1 - \delta]} \sum_{j \neq i} \left[ \frac{G_{i,t}^i y_{ijt}}{(1 - \tau_{ijt}^x)} - \frac{G_{j,t}^i y_{jit}}{(1 + \tau_{jit}^m)} \right] = - \left(1 + r_0^f\right) \frac{f_{i0}}{q_{i0}}.$$

### ***Necessary conditions for implementability***

In order to characterize the Ramsey equilibrium, we begin with a partial characterization of the set of implementable allocations for a given path of government consumption,  $\{g_{it}\}$ . A necessary condition for an allocation  $\{c_{it}, n_{it}, y_{ijt}, k_{it+1}, x_{it}\}$  and period zero policies and prices,  $\{\tau_i^W, \tau_{i0}^c, q_{i0}\}$ , given  $\{k_{i0}, b_{i0}, f_{i0}\}$ , to be implementable as a competitive equilibrium is that they must satisfy the resource constraints (2), (3), (4), and the implementability

conditions

$$(21) \quad \sum_{t=0}^{\infty} [\beta^t u_{c,t}^i c_{it} + \beta^t u_{n,t}^i n_{it}] = \mathcal{W}_{i0},$$

where

$$(22) \quad \mathcal{W}_{i0} = \frac{(1 - \tau_i^W) u_{c,0}^i}{(1 + \tau_{i0}^c)} \left[ (1 - \delta + G_{i,0}^i F_{k,0}^i) k_{i0} + Q_{-1} \frac{b_{i0}}{q_{i,0}} + (1 + r_0^f) \frac{f_{i,0}}{q_{i,0}} \right].$$

The proof of the following proposition is standard and is omitted.

**Proposition 1 (Necessary conditions for implementation):** Any implementable allocation and period zero policies and prices must satisfy the implementability constraint for each country (21) and the resource constraints (2), (3), and (4).

This proposition is useful in developing the relaxed Ramsey problem described below. Note that we are not including other conditions of the competitive equilibrium; in particular, we omit the balance of payments condition, (20).

## B. Cooperative Ramsey Equilibria

Here, we ask how fiscal policy and trade policy should be conducted when governments can cooperate in setting these policies. We show that the Ramsey allocations are production efficient as long as countries are connected through trade links. Such production efficiency in general requires tariffs on imports that are exactly offset by export subsidies.

We assume that households in each country must be allowed to keep an exogenous value of initial wealth  $\bar{\mathcal{W}}_i$ , measured in units of utility. Specifically, we impose the following restriction on the policies:

$$(23) \quad \mathcal{W}_{i0} \geq \bar{\mathcal{W}}_i,$$

which we refer to as the *wealth restriction*. With this restriction, policies, including initial policies, can be chosen arbitrarily, but the household must receive a value of initial wealth in utility terms of  $\bar{\mathcal{W}}_i$ . This restriction implicitly limits the extent of confiscation of initial wealth. In particular, it limits the tax rates on initial wealth  $\tau_i^W$ . Chari, Nicolini, and Teles

(2020) offer a rationalization and a defense of restrictions of this kind in a closed economy (see also Armenter 2008 for an analysis in a closed economy with such a restriction).

Formally, a (*cooperative*) *Ramsey equilibrium* is a competitive equilibrium that is not Pareto dominated by any other competitive equilibrium. The *Ramsey allocation* is the associated allocation.

### ***Ramsey problem***

The Ramsey problem is to choose allocations, prices and policies to maximize a weighted sum of utilities of the households of the  $N$  countries,

$$(24) \quad \sum_{i=1}^N \omega^i U^i,$$

over the set of competitive equilibria satisfying the wealth restriction, (23).

### ***Relaxed Ramsey problem***

Next we state and prove that the Ramsey allocations satisfy production efficiency. To do so, it is convenient to consider a *relaxed Ramsey problem*, which consists of choosing allocations and period zero policies to maximize the planner's objective, (24), subject to the implementability constraints, (21); the initial wealth condition, (23); and the resource constraints (2), (3), and (4). Note that these conditions are the necessary conditions described in proposition 1.

We now show that the solution to the relaxed Ramsey problem can be implemented as a Ramsey equilibrium, as long as countries are connected in a way we make precise below. To do so, we will construct policies that, together with the allocations associated with the relaxed Ramsey problem, constitute a competitive equilibrium. In particular, we will show that the balance of payments condition (20) is satisfied. Choose period zero policies to satisfy the initial wealth condition, (23), and the tax rates on consumption and labor to satisfy (15) and (16). Prices are set to satisfy the firms' and households' first-order conditions, and the household budget constraints are satisfied because the implementability conditions are imposed. The government budget constraints are implied by the other equilibrium conditions.



Choose the trade taxes so that  $\tau_{ijt}^x = -\tau_{ijt}^m$ . With these offsetting trade taxes, there are no trade wedges, as required by the production efficiency conditions (8) and (9).<sup>2</sup> The balance of payments condition (20) becomes

$$(25) \quad \sum_{t=0}^{\infty} \frac{1}{\prod_{s=0}^t [G_{i,s}^i F_{k,s}^i + 1 - \delta]} \sum_{j \neq i} \left[ \frac{G_{i,t}^i y_{ijt}}{(1 - \tau_{ijt}^x)} - \frac{G_{j,t}^i y_{jit}}{(1 - \tau_{jit}^x)} \right] = - \left( 1 + r_0^f \right) \frac{f_{i0}}{q_{i0}} \text{ for all } i.$$

To develop the assumptions needed to ensure that (25) is satisfied, we use some ideas from graph theory. We say that a pair of countries  $i, j$  is *directly linked* if there exists some  $t$  such that  $y_{ijt} \neq 0$  or  $y_{jit} \neq 0$ . Countries are *indirectly linked* if for any pair of countries  $i, j$ , there is some sequence of direct links between  $i$  and  $j$ . (In terms of language from graph theory, countries are *nodes*, direct links are *edges*, and indirect links are *paths*). The countries are *connected* if any pair of countries  $i$  and  $j$  is directly or indirectly linked. It should be clear that generically, the economies studied here will be connected.

In Appendix B we show that if countries are connected, it is possible to construct trade taxes so that (25) is satisfied.<sup>3</sup> We then have the following proposition:

**Proposition 2 (Ramsey allocations are production efficient):** If at the solution to the relaxed Ramsey problem, countries are connected, then the Ramsey allocation satisfies production efficiency.

**Remark 1:** Thus far, we have taken the perspective that goods are indexed by both their physical attributes and the location of their production and destination. We have done so to capture the idea that countries impose trade taxes that depend on those different characteristics. For example, the United States imposes tariffs on car parts imported from Mexico that are very different from those on identical parts imported from Brazil. Indeed, the entire literature on trade diversion is about different tariffs on identical goods imported from different countries.

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<sup>2</sup>Since the trade taxes exactly offset each other, the price received by producers of the intermediate good in the exporting country is the same as the price paid by users of the intermediate good in the importing country. Since the prices do not depend on the route, there are no arbitrage opportunities in exporting an intermediate good to a third country and re-exporting it to the final destination country.

<sup>3</sup>Recall that we have assumed initial foreign assets are fixed in real terms. If, instead, we had assumed that initial foreign assets were fixed in nominal terms, an additional channel that would be available to help satisfy (25) is to appropriately choose  $q_{i0}$  for each country. These choices can be thought of as choices of the initial exchange rates.

While a realistic formulation demands that we index goods in the way we do, in order to relate our results to the literature, we turn now to a more restrictive formulation in which goods are indexed only by their physical attributes. We restrict policies so that import tariffs can depend only on the identity of the good and of the importing country, and not on the identity of the origin country. Similarly, we restrict export subsidies to depend only on the identity of the good and the exporting country.

In Appendix B, we develop a simple static example with more countries than goods and show that the Ramsey allocation with these restrictions does not satisfy production efficiency. The reason is that with these restrictions, trade taxes cannot be chosen to simultaneously satisfy production efficiency and (20). We go on to show, in a dynamic extension of this simple example, that the Ramsey allocations do satisfy production efficiency. The reason now is that since taxes are allowed to be different across time, we effectively have more goods than countries and therefore have enough degrees of freedom to simultaneously satisfy production efficiency and (20).

These restrictions help us understand the result in Keen and Wildasin (2004) that with more countries than goods, the Ramsey allocation can be production inefficient. Simply put, Keen and Wildasin impose the restrictions that tariffs cannot depend on the origin/destination pair of trade. In our view, restrictions of this type are of very limited applied interest, given that countries routinely impose different tariffs on the same physical good based on country of origin or destination.

**Remark 2:** Proposition 2 requires that countries be connected at the solution to the relaxed Ramsey problem. If at the solution to the relaxed Ramsey problem, countries are not connected, then the relaxed Ramsey can be implemented with government to government transfers, as described below, and cannot be implemented by offsetting trade taxes. A small perturbation of the original environment will ensure that, in this case, the countries are connected. Thus, we do not view the requirement of connectedness as very stringent.

**Remark 3:** Inspection of (25) makes clear that this equation can be satisfied by many paths of trade taxes. Indeed, these trade taxes can be chosen in a continuum of ways so that there is indeterminacy. This indeterminacy result can also hold even if we restrict trade taxes so that they do not depend on the origin/destination pair. See Maggi and Rodríguez-Clare

(2005) for a proof of indeterminacy with such a restriction.

We now characterize the Ramsey equilibrium in greater detail. To do so, it is useful to define

$$v^i(c_{it}, n_{it}; \varphi^i) = u^i(c_{it}, n_{it}) + \varphi^i [u_{c,t}^i c_{it} + u_{n,t}^i n_{it}],$$

where  $\omega^i \varphi^i$  is the multiplier of the implementability condition (21). The relaxed Ramsey problem then reduces to maximize

$$\sum_{i=1}^N \omega^i \left[ \sum_{t=0}^{\infty} \beta^t [v^i(c_{it}, n_{it}; \varphi^i) + h^i(g_{it})] - \varphi^i \bar{W}_i \right],$$

subject to the resource constraints (2) and (5).

The solution of the relaxed Ramsey problem satisfies

$$(26) \quad -\frac{v_{c,t}^i}{v_{n,t}^i} = \frac{1}{G_{i,t}^i F_{n,t}^i},$$

$$(27) \quad \frac{v_{c,t}^i}{\beta v_{c,t+1}^i} = 1 - \delta + G_{i,t+1}^i F_{kt+1}^i,$$

together with the production efficiency conditions, (8) and (9).

These equations imply an analog of the intertemporal consumption efficiency condition

$$(28) \quad \frac{v_{c,t}^i}{\beta v_{c,t+1}^i} \frac{G_{j,t}^i}{G_{j,t+1}^i} \text{ is the same across countries } i.$$

In Appendix C, we report the first-order conditions for the optimal levels of government consumption.

Note that

$$v_{c,t}^i = u_{c,t}^i [1 + \varphi^i (1 + \sigma_t^{in} - \sigma_t^{inc})] \quad \text{and} \quad v_{n,t}^i = u_{n,t}^i [1 + \varphi^i (1 + \sigma_t^i - \sigma_t^{icn})],$$

where  $\sigma_{cct}^i$  and  $\sigma_{nnt}^i$  are the own elasticities of the marginal utilities of consumption and labor; and  $\sigma_{nct}^i$  and  $\sigma_{cnt}^{icn}$  are the cross elasticities. In general, these own and cross elasticities depend

on the allocations and vary across countries and over time. Thus, in general, the ratios of the derivatives of the  $v^i$  functions do not coincide with the marginal rates of substitution, and the wedges vary across countries. In particular,

$$(29) \quad \frac{-v_{c,t}^i/v_{n,t}^i}{-u_{c,t}^i/u_{n,t}^i} \neq \frac{-v_{c,t}^j/v_{n,t}^j}{-u_{c,t}^j/u_{n,t}^j} \quad \text{and} \quad \frac{v_{c,t}^i/\beta v_{c,t+1}^i}{u_{c,t}^i/\beta u_{c,t+1}^i} \neq \frac{v_{c,t}^j/\beta v_{c,t+1}^j}{u_{c,t}^j/\beta u_{c,t+1}^j}.$$

Inspecting (26) and (27) and their analogs in the competitive equilibrium, (15) and (16), we find that the taxes on consumption and labor that implement the Ramsey equilibrium are given by

$$(30) \quad \frac{-u_{c,t}^i/u_{n,t}^i}{-v_{c,t}^i/v_{n,t}^i} = \frac{(1 + \tau_{it}^c)}{(1 - \tau_{it}^n)},$$

$$(31) \quad \frac{u_{c,t}^i/\beta u_{c,t+1}^i}{v_{c,t}^i/\beta v_{c,t+1}^i} = \frac{(1 + \tau_{it}^c)}{(1 + \tau_{it+1}^c)}.$$

**Remark 4:** Inspecting (29), (30) and (31) we see that tax wedges are, in general, not equated across countries. In this sense, tax harmonization is not necessarily optimal.

**Remark 5:** Comparing (26) and (27) with (30) and (31), we see that the tax wedges are, in general, time varying. Thus, taxes will generally also be time varying.<sup>4</sup>

Thus far, we have considered the general case of  $N > 2$  countries. Having more than two countries is essential in understanding the role of restrictions on policies discussed in Remark 1. In the remainder of the paper, in order to reduce the notational burden, we restrict our analysis to two countries. It should be clear that all our results go through for  $N > 2$  countries.

### *Allowing for transfers*

Thus far, we have not allowed governments to make lump-sum transfers to each other. Here, we allow for such transfers and show that with transfers, efficient allocations can be supported by policies that set all tariffs and export taxes to zero and use only consumption and labor income taxes. This result clarifies that the role of offsetting trade tariffs and

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<sup>4</sup>See Chari, Nicolini, and Teles (2020) for relationships between these results and those in the closed economy literature.

subsidies is solely redistributive across governments. Without loss of generality, we assume that country  $i$  makes a (net) transfer  $T_{i0}$  to the other country. The budget constraint for the government of country  $i$ , (13), becomes

$$(32) \quad \sum_{t=0}^{\infty} Q_t \left[ \tau_{it}^c q_{it} c_{it} + \tau_{it}^n w_{it} n_{it} + \sum_{j \neq i} \tau_{jit}^m p_{jit} y_{jit} + \sum_{j \neq i} \tau_{ijt}^x p_{ijt} y_{ijt} - q_{it} g_{it} \right] = Q_{-1} b_{i0} - T_{i0} - \tau_i^W a_{i0}.$$

Since transfers made by one government are received by the other, we have

$$(33) \quad \sum_{i=1}^2 T_{i0} = 0.$$

Combining the budget constraints of the government and the household (with equality) in each country, we obtain a rewritten version of the balance of payments condition, (14):

$$(34) \quad \sum_{t=0}^{\infty} Q_t \sum_{j \neq i} [p_{ijt} y_{ijt} - p_{jit} y_{jit}] = - (1 + r_0^f) f_{i,0} - T_{i0},$$

for all  $i$ .

The Ramsey problem in this case is to choose policies, allocations, and initial transfers. Since transfers appear only in the balance of payments condition (34), we can simply drop constraint (34), and the Ramsey problem with transfers coincides with the relaxed Ramsey problem. This result implies that the offsetting trade taxes in the Ramsey equilibrium without transfers can be replaced by explicit transfers. The level of the transfers is uniquely pinned down by the welfare weights of the Ramsey problem. In this sense, the offsetting trade taxes play a purely redistributive role. We summarize this result in the following proposition.

**Proposition 3 (Optimality of explicit free trade):** If governments can make transfers to each other, the Ramsey allocations can be implemented by setting all trade taxes to zero.

For all the results that follow, unless explicitly stated to the contrary, we assume that direct transfers are available and that trade taxes are not used for redistribution across

countries.<sup>5</sup>

The logic behind propositions 2 and 3 can be extended to show that restrictions on capital mobility are not efficient. To see this result, consider, for example, allowing the Ramsey planner to impose capital controls. One way of allowing for capital controls is to impose constraints on the foreign assets that residents of country  $i$  can hold, so that households face additional constraints of the form  $f_{it} \leq \bar{f}_{it}$ , where  $\bar{f}_{it}$  is chosen by the planner. Using the evolution of household wealth, we can alternatively represent the constraints as

$$(35) \quad \sum_{s=0}^{\infty} Q_{t+s} [q_{it+s} (1 + \tau_{it+s}^c) c_{it+s} - (1 - \tau_{it+s}^n) w_{it+s} n_{it+s}] \leq V_{it} + d_{it} + Q_{t-1} b_{it} + (1 + r_0^f) \bar{f}_{it}, \quad t \geq 1.$$

These are additional constraints on the Ramsey problem that can be written in terms of the allocations. Thus, in the solution to the cooperative Ramsey problem, it is optimal to set  $\bar{f}_{it}$  to be sufficiently large so that these additional constraints are never binding. The same logic applies to any other restrictions on capital mobility, including taxes on capital flows. In this sense, the logic behind proposition 2 implies that unrestricted capital mobility is optimal in a cooperative Ramsey equilibrium.

We next turn to proving an analog of the first welfare theorem. We will show that there is a pair of welfare weights,  $\omega^1$  and  $\omega^2$ , such that the government-to-government transfers are zero. Without loss of generality, let  $\omega^1 = \omega \in [0, 1]$  and  $\omega^2 = 1 - \omega$ . Let  $T^i(\omega)$  denote the transfers to country  $i$  under the Ramsey allocation associated with welfare weight  $\omega$ .

**Proposition 4 (Optimality of production efficiency with zero transfers):** Assume  $\bar{W}_i$  and  $f_{i0}$  are sufficiently close to zero for  $i = 1, 2$ . There exists a weight  $\omega \in [0, 1]$  such that transfers are zero:  $T^i(\omega) = 0$ ,  $i = 1, 2$ .

**Proof:** Under our differentiability and interiority assumptions, the transfer functions  $T^i(\omega)$ ,  $i = 1, 2$  are continuous. In Appendix C, we show that  $T^1(0) \leq 0$  and  $T^1(1) \geq 0$ . The result follows from the intermediate value theorem. ■

**Remark:** The same theorem holds with more than two countries. In this case, we

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<sup>5</sup>If direct transfers are not available, all the results below go through with trade taxes used solely for redistributive purposes.

can apply the argument in Negishi (1972) to prove the result.

In Appendix C, we explain the role of the technical assumption that  $\bar{\mathcal{W}}_i$  is sufficiently close to zero and make clear that for a (potentially large) neighborhood of promised wealth around zero, the proposition goes through.

This proposition says that there is a vector of welfare weights such that no transfers (or trade taxes) are needed to implement the cooperative Ramsey equilibrium. Thus, if the economy starts off at this Ramsey allocation, no Pareto improvement is possible.

### C. Allowing for Distributional Considerations

In the model above, we abstract from the distributional effects of policies within each country. In this section, we briefly address those considerations, allowing for the possibility that different agents may be differently affected by trade policies. For simplicity, we consider only two worker types with equal mass. The production function in country  $i$  is described by

$$y_{i1t} + y_{i2t} = y_{it} = F^i(k_{it}, n_{it}^a, n_{it}^b),$$

where  $n_{it}^a$  and  $n_{it}^b$  are the labor hours of agents  $a$  and  $b$  in country  $i$ . Notice that with this production function, the relative wages of the two agents are endogenous and are a function of trade policies. A special case in which the relative wage is exogenous is when the two agent types differ only in their efficiency units but are perfect substitutes in production, as in  $F^i(k_{it}, n_{it}^a + \eta_i n_{it}^b)$ . The preferences of type  $a$  agents are

$$U^{ia} = \sum_{t=0}^{\infty} \beta^t [u^{ia}(c_{it}^a, n_{it}^a) + h^i(g_{it})]$$

and are similar for type  $b$  agents.

An allocation in this economy consists of consumption and labor allocations for each household  $a$  and  $b$ ,  $\{c_{it}^a, n_{it}^a\}$  and  $\{c_{it}^b, n_{it}^b\}$ , and aggregate allocations for each country  $\{y_{ijt}, k_{it+1}, x_{it}\}$ . The market clearing condition for the final good is

$$c_{it}^a + c_{it}^b + g_{it} + x_{it} \leq G^i(y_{1it}, y_{2it}),$$

and the capital accumulation equation is (4).

We start by allowing for a version of our benchmark system with transfers across countries. In this version, the government in each country can impose taxes that are specific to each type of agent on consumption and labor income and initial wealth. The planner must also respect the wealth constraints for each type of agent in each country.

In this case, it is straightforward to show that proposition 2 holds, so that restrictions on trade and capital mobility are not optimal.

Suppose instead that the tax rates on the two types of agents are restricted so that they are the same within a country. Then, the following additional implementability conditions must be imposed:

$$-\frac{u_{c^a,t}^i F_{n^a,t}^i}{u_{n^a,t}^i} = -\frac{u_{c^b,t}^i F_{n^b,t}^i}{u_{n^b,t}^i},$$

and

$$\frac{u_{c^a,t}^i}{\beta u_{c^a,t+1}^i} = \frac{u_{c^b,t}^i}{\beta u_{c^b,t+1}^i}.$$

With these extra restrictions, production efficiency may not be optimal.<sup>6</sup>

### III Alternative Implementations

Thus far, we have considered tax systems that include taxes on consumption, labor income, and trade. Here, we discuss a variety of other tax systems, including taxes on the income from different assets and value-added taxes. As mentioned above, we assume that direct transfers are available to redistribute across countries. Trade taxes are used only if needed to achieve efficiency.

Our analysis is motivated by the observation that these alternative tax systems are widely used in practice. We show that no tax system can yield higher welfare than the tax system with only consumption and labor income taxes. We show that a variety of tax systems can implement the Ramsey allocation associated with those taxes. Furthermore, some tax

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<sup>6</sup>For particular cases in which production efficiency is still optimal, see the preference and technology specifications in the closed economy model of Chari, Nicolini and Teles (2020).



systems do yield lower welfare.

### A. Taxes on Corporate Income and Asset Returns

Here, we consider a tax system that consists of taxes on labor income, on corporate income, and on the returns of households' asset holdings. We assume that tax rates on household asset income are the same for all assets. We show that the Ramsey outcome can be implemented with zero taxation of corporate income and with suitably chosen taxes on household asset income. We also show that non-zero corporate income taxation can impose intertemporal trade wedges. This result shows that free trade agreements need to be supplemented with agreements on fiscal policy.

We now describe the problems of the firms and the household in each country and define a competitive equilibrium.

#### *Firms*

The representative intermediate good firm in each country produces and invests in order to maximize the present value of dividends,  $V_{i0} + d_{i0} = \sum_{t=0}^{\infty} Q_t d_{it}$ , where  $Q_t$  is the pretax discount factor. Dividends,  $d_{it}$ , in units of the numeraire, are given by

$$(36) \quad \begin{aligned} d_{it} &= p_{it}F(k_{it}, n_{it}) - w_{it}n_{it} - \tau_{it}^k [p_{it}F(k_{it}, n_{it}) - w_{it}n_{it} - q_{it}\delta k_{it}] \\ &\quad - q_{it} [k_{it+1} - (1 - \delta)k_{it}], \end{aligned}$$

where  $\tau_{it}^k$  is the tax rate on corporate income net of depreciation. Here, we have specified the tax base for corporate income in the standard way. Below, we describe an alternative tax base, which allows for investment expenses to be deducted.

Note that one of the first-order conditions of the firm's problem is

$$(37) \quad \frac{Q_t q_{it}}{Q_{t+1} q_{it+1}} = 1 + (1 - \tau_{it+1}^k) \left( \frac{p_{it+1}}{q_{it+1}} F_{k,t+1}^i - \delta \right).$$

We use this condition in the proof of proposition 5, below.

The problem of the final good firm is as it was before.

## Households

Here we explicitly allow for sequential trading by households. In each period, households choose consumption, labor supply, and holdings of domestic and foreign bonds and equity in domestic firms. For simplicity, and without loss of generality, we assume that households cannot hold foreign equity.

The tax base for bond income, expressed in real terms, is given by  $(r_t^f - (q_{it} - q_{it-1})/q_{it-1})(f_{it} + b_{it})$ . This way of defining the base ensures that taxes are levied only on real income. The tax base for equity income taxation is given by

$$d_{it} + V_{it} - V_{it-1} - (q_{it} - q_{it-1})V_{it-1}/q_{it-1}$$

per share. Note that this tax base includes dividends received in the current period and accrued capital gains generated by changes in the price of equity, as well as an adjustment to ensure that the base is expressed in real terms.

The flow of funds constraint in period  $t \geq 1$  for the household in country  $i$  in units of the numeraire is then given by

$$(38) \quad \begin{aligned} & q_{it}c_{it} + b_{it+1} + f_{it+1} + V_{it}s_{it+1} \\ = & (1 - \tau_{it}^n)w_{it}n_{it} + \left[ 1 + r_t^f - \tau_{it} \left( r_t^f - \frac{q_{it} - q_{it-1}}{q_{it-1}} \right) \right] (f_{it} + b_{it}) \\ & + (V_{it} + d_{it})s_{it} - \tau_{it} \left( d_{it} + V_{it} - V_{it-1} - \frac{(q_{it} - q_{it-1})V_{it-1}}{q_{it-1}} \right) s_{it}. \end{aligned}$$

The period zero constraint needs to be adjusted by the wealth tax and is given in Appendix D. Note that since domestic and foreign bond income are taxed at the same rate in each country, the pretax returns on bonds are the same in the two countries.

The household's problem is to maximize utility (1), subject to (38) and the relevant budget constraint at period zero and no-Ponzi conditions,  $\lim_{T \rightarrow \infty} Q_{iT+1}b_{iT+1} \geq 0$  and  $\lim_{T \rightarrow \infty} Q_{iT+1}f_{iT+1} \geq 0$ , where  $Q_{it}/Q_{it+1}$  is the return on bonds net of taxes given by

$$\frac{Q_{it}}{Q_{it+1}} = (1 - \tau_{it+1}) \left( 1 + r_{t+1}^f \right) + \tau_{it+1} \frac{q_{it+1}}{q_{it}} \text{ with } Q_{i0} = 1.$$

Using the no-Ponzi-scheme condition, we can consolidate the budget constraints of the

household, (38) and the period zero budget constraint into the single budget constraint,

$$\sum_{t=0}^{\infty} Q_{it} [q_{it} c_{it} - (1 - \tau_{it}^n) w_{it} n_{it}] = (1 - \tau_i^W) a_{i0},$$

where the expression for the initial wealth,  $a_{i0}$ , is given in Appendix D.

It is straightforward to show that the consolidated budget constraint reduces to the same implementability constraint, (21), with  $\mathcal{W}_{i0}$  given in Appendix D. It is also straightforward to show that any allocation that satisfies the implementability and resource constraints can be implemented as a competitive equilibrium.<sup>7</sup>

The Ramsey problem is then to maximize (24) subject to the implementability constraints (21), with the wealth restriction (23) and the resource constraints. It is immediate that the Ramsey allocation in the economy with consumption and labor income taxes coincides with the one in the economy considered here.

Next, we show that it is optimal to set corporate income taxes to zero and that, in general, asset taxes are needed to implement the Ramsey outcome. It is straightforward to show that if we use the first-order conditions of the firms, any competitive equilibrium satisfies static production efficiency. Next, we turn to conditions that implement dynamic production efficiency. Using (37) for both countries, as well as the final good firms' conditions, we obtain a version of the interest rate parity condition:

$$(39) \quad \begin{aligned} & \frac{G_{j,t}^1}{G_{j,t+1}^1} [1 + (1 - \tau_{1,t+1}^k) (G_{1,t+1}^1 F_{k,t+1}^1 - \delta)] \\ & = \frac{G_{j,t}^2}{G_{j,t+1}^2} [1 + (1 - \tau_{2,t+1}^k) (G_{2,t+1}^2 F_{k,t+1}^2 - \delta)], \text{ for } j = 1, 2. \end{aligned}$$

Comparing this condition with (9), we see that setting both corporate income taxes to zero ensures dynamic production efficiency. It is also clear that, if one of the countries sets the corporate income tax equal to zero, the other country can impose wedges on intertemporal trade by setting a tax rate different from zero. Comparing (18) with (39), we see that these wedges are similar to the ones that arise with time varying tariffs. We summarize this result

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<sup>7</sup>If there were multiple consumption goods in each period, consumption taxes on those goods might be needed.

in the following proposition.

**Proposition 5 (Corporate income taxes and capital mobility):** Non-zero corporate income taxes introduce wedges in international intertemporal trade.

Next, we show that asset taxes are needed to implement the Ramsey allocation. To do so, we use the households' and firms' first-order conditions to obtain

$$(40) \quad -\frac{u_{c,t}^i}{u_{n,t}^i} = \frac{1}{(1 - \tau_{it}^n) G_{i,t}^i F_{n,t}^i}$$

and

$$(41) \quad \frac{u_{c,t}^i}{\beta u_{c,t+1}^i} = 1 + (1 - \tau_{it+1}) (1 - \tau_{it+1}^k) (G_{i,t+1}^i F_{k,t+1}^i - \delta).$$

In general, the solution to the Ramsey problem requires time-varying intertemporal distortions. Thus, implementing the Ramsey outcome with the system considered here requires asset taxes, given that the corporate income tax is set to zero. If we set the asset taxes to zero, it is in general not possible to choose the corporate income tax rates in both countries to satisfy both (39) and (41) at the Ramsey allocation.

We summarize these results in the following proposition.

**Proposition 6 (Common tax on domestic equity and foreign returns):** The Ramsey outcome can be implemented with labor income taxes and asset taxes and by setting the corporate income taxes to zero. In general, the Ramsey outcome cannot be implemented with only labor income taxes and corporate income taxes.

**Remark 1:** These results are quite different from those in a closed economy. In a closed economy, household asset taxes and corporate income taxes distort capital accumulation in the same way. Thus, it is possible to support the Ramsey allocations with labor income taxes and corporate income taxes or, equivalently, with labor income taxes and household asset taxes. In the open economy, a system with corporate income taxes distorts dynamic production efficiency by distorting the allocation of capital across countries in addition to distorting capital accumulation. In this sense, a system with corporate income taxes is dominated by a system with household asset taxes.

**Remark 2:** Note that we have assumed that the tax rates on domestic and foreign

asset income are the same. If these tax rates are allowed to be different, then the Ramsey equilibrium can be implemented by setting them so that they coincide.

**Remark 3:** Our analysis allows for a comparison of residence-based and source-based tax systems. In our model, a residence-based system is one in which all household asset income is taxed at a rate that is independent of where the income is generated but can depend on where the household resides. A source-based system is one in which income is taxed where it is generated—namely, at a point of production. A corporate income tax is an example of a source-based system. Since we have argued that household asset taxes have advantages over corporate income taxes, we have shown that residence-based tax systems have advantages over source-based systems.

**Remark 4:** In our discussion so far, we have assumed that investment expenditures are not deductible in calculating the base for corporate income taxation. An alternative formulation is to allow investment expenditures to be deductible. In this case, the dividends are given by

$$d_{it} = p_{it}F(k_{it}, n_{it}) - w_{it}n_{it} - q_{it}[k_{it+1} - (1 - \delta)k_{it}] \\ - \tau_{it}^k [p_{it}F(k_{it}, n_{it}) - w_{it}n_{it} - q_{it}(k_{it+1} - (1 - \delta)k_{it})]$$

If we adapt the arguments on the optimal taxation of capital income in a closed economy (see, for example, Chari, Nicolini, and Teles (2020)), it is possible to show that a constant corporate income tax, with suitably time-varying consumption and labor taxes, can implement the Ramsey allocation. Interestingly, in the global economy, a tax rate that is the same across countries, but varies over time, can also be part of the implementation of the Ramsey allocation (see Appendix D for a proof of these results). This remark helps clarify that, as is well known, the Ramsey allocation can be implemented in a variety of ways, so that Ramsey outcomes pin down wedges, rather than specific patterns of taxes.

Our analysis clarifies the discussion on the desirability of corporate income taxation. The conventional wisdom in this area is well summarized in the 2007 OECD Volume *Fundamental Reform of Corporate Income Tax*:<sup>8</sup>

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<sup>8</sup>We thank a referee for suggesting that we include this clarification.

“The main reason for imposing a corporate tax is that the tax plays an important withholding function, acting as a ‘backstop’ to the personal income tax. The corporate tax might be needed to avoid excessive income shifting between labour income and capital income. The corporate tax also acts as a withholding tax on equity income earned by non-resident shareholders, which might otherwise escape taxation in the source country. Moreover, governments might levy a corporate income tax because firms earn location-specific rents and/or because capital is not perfectly mobile.”

We view the backstop function as suggesting that it might be administratively easier to collect taxes at the source. In this case, our discussion in Remark 4 suggests that corporate income taxes on a properly defined base that are constant over time or the same across countries, together with other suitably designed taxes, can implement Ramsey outcomes. Second, to the extent that, for administrative reasons, taxes on asset income earned by non-residents are taxed, our analysis suggests that one way of implementing the Ramsey allocation is to have these revenues rebated to the destination country along suitable adjustments in taxation in the destination country. Third, our environment can be easily adapted to allow for fixed factors in production, as long as the income from these factors is taxed at a rate that meets the initial wealth constraint. In this case, the corporate income tax could be one way of raising taxes on fixed factors, but it will require the base to exclude investment expenses.

We have considered a decentralization in which investment decisions are made by firms. Much of the macroeconomics literature considers decentralizations in which investment decisions are made by households and firms simply rent capital and labor from households. It is possible to show that with this decentralization, the same Ramsey outcomes can be supported by a tax system under which household assets are taxed at a rate that may vary across countries but is uniform across asset types.

## **B. Border-Adjusted Value-Added Taxes and Labor Income Taxes**

Consider next an economy in which consumption taxes are replaced by value-added taxes levied on firms with border adjustment. Border adjustment means that firms in a country do not pay value-added taxes on exports and cannot deduct imports. Taxes on assets are set to zero, but labor income taxes are not. The value-added taxes are denoted by

$\tau_{it}^v$ . We refer to the system with value-added taxes with border adjustment as a *VAT with BA system*.

The intermediate goods firm now maximizes

$$(42) \quad \sum_{t=0}^{\infty} Q_t [(p_{i1t}y_{i1t} + p_{i2t}y_{i2t}) - w_{it}n_{it} - q_{it}x_{it}] - \sum_{t=0}^{\infty} Q_t \tau_{it}^v [p_{iit}y_{iit} - q_{it}x_{it}],$$

subject to (2) and (4), where  $p_{ijt}$  is the price of the intermediate good produced in country  $i$  and sold in country  $j$ . Note that the final goods firm pays taxes on the good when it is sold domestically, but not when it is exported. In this sense, taxes are adjusted at the border.

The final goods firm now maximizes

$$(43) \quad \sum_{t=0}^{\infty} Q_t [q_{it}G^i(y_{1it}, y_{2it}) - p_{1it}y_{1it} - p_{2it}y_{2it}] - \sum_{t=0}^{\infty} Q_t \tau_{it}^v [q_{it}G^i(y_{1it}, y_{2it}) - p_{iit}y_{iit}].$$

This firm is able to deduct the input produced domestically, but not the one imported. Thus, taxes are again adjusted at the border. The household problem is the same as it was above, except that the consumption taxes are set to zero.

In Appendix E, we show that the equilibrium conditions in this economy with VAT with BA are

$$(44) \quad -\frac{u_{c,t}^i}{u_{n,t}^i} = \frac{1}{(1 - \tau_{it}^n)(1 - \tau_{it}^v)G_{i,t}^i F_{n,t}^i}, \quad t \geq 0,$$

$$(45) \quad u_{c,t}^i (1 - \tau_{it}^v) = (1 - \tau_{it+1}^v) \beta u_{c,t+1}^i [G_{i,t+1}^i F_{k,t+1}^i + 1 - \delta], \quad t \geq 0,$$

together with the production efficiency conditions. Clearly, these conditions coincide with those in an economy with only consumption and labor income taxes if the value-added taxes satisfy

$$(46) \quad 1 + \tau_{it}^c = \frac{1}{1 - \tau_{it}^v}.$$

The proposition follows.

**Proposition 7 (Value-added taxes with border adjustment):** A value-added

tax system with border adjustment, including labor income taxes, is equivalent to a system that taxes consumption and labor and has no tariffs.

Since the Ramsey allocation can be implemented by a system that taxes only consumption and labor, this proposition implies that the Ramsey allocations can be implemented by a value-added tax system with border adjustments. In this sense, a value-added tax system with border adjustments has desirable features.

Consider an environment where countries agree to free trade and commit to using a VAT with BA system, but they are free to set tax rates as they see fit. Notice that in this non-cooperative setting, they will not be able to use fiscal policy to impose trade wedges. Thus, the design of tax systems affects the extent to which fiscal policy is trade policy. Of course, countries could always use fiscal policy to affect international terms of trade. This proposition establishes that if countries are constrained to adopt VAT with border adjustments, they cannot introduce trade wedges.

### C. Value-Added Taxes without Border Adjustment: The Role of Tariffs

Consider next an economy just like the one in the previous section, except that value-added taxes are levied on firms without border adjustment. This means that the taxation of intermediate goods will be origin based. Here, we allow for trade taxes, because as it turns out, they may be needed to achieve efficiency. We refer to the system with value-added taxes without border adjustment and with trade taxes as a *VAT without BA system*. We will show that this system with trade taxes set to zero cannot in general implement the Ramsey allocation. We show that the system with non-zero trade taxes can implement the Ramsey allocation.

The intermediate goods firm in country 1 now maximizes

$$\sum_{t=0}^{\infty} Q_t [(1 - \tau_{1t}^v) (p_{11t}y_{11t} + (1 - \tau_{12t}^x) p_{12t}y_{12t} - q_{1t}x_{1t}) - w_{1t}n_{1t}],$$

subject to (2) and (4).



The final goods firm in country 1 now maximizes

$$\sum_{t=0}^{\infty} Q_t (1 - \tau_{1t}^v) [q_{1t} G^1(y_{11t}, y_{21t}) - p_{11t} y_{11t} - (1 + \tau_{21t}^m) p_{21t} y_{21t}].$$

Firms in country 2 solve similar problems.

The first-order conditions of the household and firms can be used to obtain (44), (45), and

$$(47) \quad \frac{(1 + \tau_{21t}^m) G_{2,t}^2}{(1 - \tau_{21t}^x) G_{2,t}^1} = \frac{(1 - \tau_{12t}^x) G_{1,t}^2}{(1 + \tau_{12t}^m) G_{1,t}^1},$$

$$(48) \quad \begin{aligned} & \frac{(1 + \tau_{12t}^m) (1 - \tau_{12t+1}^x) (1 - \tau_{1t+1}^v) G_{1,t}^1}{(1 - \tau_{12t}^x) (1 + \tau_{12t+1}^m) (1 - \tau_{1t}^v) G_{1,t+1}^1} [G_{1,t+1}^1 F_{k,t+1}^1 + 1 - \delta] \\ &= \frac{(1 - \tau_{2t+1}^v) G_{1,t}^2}{(1 - \tau_{2t}^v) G_{1,t+1}^2} [G_{2,t+1}^2 F_{k,t+1}^2 + 1 - \delta]. \end{aligned}$$

Using (45) and (48), we obtain the analog to (19),

$$(49) \quad \frac{(1 + \tau_{12t}^m) / (1 - \tau_{12t}^x) u_{c,t}^1}{(1 + \tau_{12t+1}^m) / (1 - \tau_{12t+1}^x) \beta u_{c,t+1}^1} = \frac{u_{c,t}^2}{\beta u_{c,t+1}^2} \frac{G_{1,t}^2 / G_{1t}^1}{G_{1,t+1}^2 / G_{1t+1}^1}.$$

We use these conditions to show that if trade taxes are constrained to be zero in both countries, it is not possible to implement the Ramsey outcome for general preferences. Recall from (28) that in a Ramsey outcome,

$$\frac{v_{c,t}^1}{\beta v_{c,t+1}^1} \frac{G_{j,t}^1}{G_{j,t+1}^1} = \frac{v_{c,t}^2}{\beta v_{c,t+1}^2} \frac{G_{j,t}^2}{G_{j,t+1}^2},$$

so that, from (29), we see that in general,

$$(50) \quad \frac{u_{c,t}^1}{\beta u_{c,t+1}^1} \frac{G_{j,t}^1}{G_{j,t+1}^1} \neq \frac{u_{c,t}^2}{\beta u_{c,t+1}^2} \frac{G_{j,t}^2}{G_{j,t+1}^2}.$$

Comparing (49) and (50), we see that with zero trade taxes, it is not possible to implement the Ramsey outcome in general.

Once we allow for tariffs, it is possible to implement the Ramsey outcome. To ensure static production efficiency, tariffs have to compensate each other so that (47) coincides with (8). To ensure dynamic production efficiency, the tariffs have to suitably vary over time so as to undo the distortions arising from time-varying VATs. One implementation of the Ramsey outcome has

$$(51) \quad \frac{1 - \tau_{1t}^v}{1 - \tau_{2t}^v} = \frac{1 - \tau_{21t}^x}{1 + \tau_{21t}^m} = \frac{1 + \tau_{12t}^m}{1 - \tau_{12t}^x}.$$

It is straightforward to verify that with these policies, it is possible to implement the Ramsey allocation. This implementation has value-added tax rates that are the same as the ones in the VAT with BA system and an effective export subsidy on good 2 and an effective import tax on good 1 of the same magnitude as the ratio of the two VATs,  $(1 - \tau_{1t}^v) / (1 - \tau_{2t}^v)$ . Trade taxes chosen in this fashion do not distort static production efficiency, and they correct for the dynamic production inefficiencies induced by time-varying VATs.

We state these results in the following proposition.

**Proposition 8 (Value-added taxes without border adjustment):** Suppose trade taxes are constrained to be zero in both countries. Then, for general preferences, the Ramsey allocation cannot be implemented with a tax system with labor income taxes and value-added taxes without border adjustment. If trade taxes are unconstrained, then the Ramsey allocation can be implemented with consumption taxes replaced by value-added taxes and tariffs.

**Remark 1:** The equilibrium conditions in this system illustrate the sense in which fiscal policy is trade policy. Consider an environment, paralleling our earlier discussion, where countries agree to free trade and commit to using a VAT without BA system, being free to set tax rates as they see fit. In this non-cooperative setting, countries will be able to use fiscal policy to impose trade wedges. To see this result, note from (48) that time-varying value-added taxes impose intertemporal trade wedges. This observation implies that countries have an incentive to use time-varying taxes to directly affect international terms of trade, just as in the optimal tariff literature. These findings reinforce the observation that the design of

tax systems affects the extent to which fiscal policy is trade policy.

Proposition 8 is connected to results in international trade. Some of the literature in international economics (e.g., Grossman 1980, Feldstein and Krugman 1990, Costinot and Werning 2018) has argued that VAT systems with border adjustment are equivalent to VAT systems without such adjustment, holding trade taxes constant. The version of the result applicable to our analysis (see Grossman 1980) is that a uniform value-added tax with border adjustment is equivalent to a uniform value-added tax without border adjustment, in the sense that, taking international prices as given, an individual country can achieve the same allocations with either system. (The theorem requires qualifications regarding the availability of initial wealth taxes to ensure that the government's budget is balanced and international lump-sum transfers to ensure that the balance of payments condition is satisfied.)

The key requirement in Grossman's version of the theorem is that value-added taxes are the same across all goods. If value-added taxes differ across goods, then the two systems are not in general equivalent. We can think of our dynamic economy as a static economy with an infinite number of goods. Suppose that the dynamic economy has constant value-added taxes over time. Then, in the reinterpreted static economy, value-added taxes are the same across all goods. Inspecting the marginal conditions with BA—namely, (8) and (9)—and those without BA—namely, (47) and (48)—we see that the same allocations can be supported by a VAT with BA system and a VAT without BA system, with no tariffs in either case. Suppose next that in the dynamic economy, value-added taxes vary over time, so that in the reinterpreted static economy, value-added taxes are different across goods. Then, inspecting the same conditions, we see that the two systems are not equivalent in the absence of tariffs.

Our results can also be used to compare destination- versus origin-based systems. To see this comparison, recall that a destination-based system is one in which tax rates do not depend on origin, and an origin-based system is one in which tax rates do not depend on destination. In the case of value-added taxes with border adjustment, the goods leave the country untaxed and are taxed at the single value-added tax rate in the destination country. In this sense, the VAT with BA system is destination-based. With value-added taxes without border adjustments, goods are taxed at the single rate of the origin country, so that a VAT without BA system is origin-based. Our results imply that if countries are restricted from

imposing trade taxes, then a destination-based system dominates an origin-based system.

#### D. Lerner Symmetry

The arguments in the previous section make clear that any competitive equilibrium allocation in a VAT without BA system and no trade taxes can be implemented in a VAT with BA system with the same VAT rates and trade taxes chosen according to (51). The trade taxes are an effective import tariff and an export subsidy of the same magnitude. The results regarding the conditions under which VAT with and without border adjustments are equivalent are related to Lerner symmetry. In a static two-good economy, Lerner symmetry asserts that an import tariff is equivalent to an export tax. To understand the relationship with our results, we begin with the following lemma, which establishes a version of Lerner symmetry for our dynamic model.

**Lemma 1 (Lerner (a)symmetry):** The competitive equilibrium allocations of an economy with trade taxes given by  $\tau_{12t}^x$  and  $\tau_{21t}^m$  coincide with the competitive equilibrium allocations with trade taxes  $\hat{\tau}_{12t}^x$  and  $\hat{\tau}_{21t}^m$  satisfying  $(1 - \hat{\tau}_{12t}^x) = \kappa_t (1 - \tau_{12t}^x)$  and  $(1 + \hat{\tau}_{21t}^m) = \kappa_t (1 + \tau_{21t}^m)$ , if and only if  $\kappa_t = \kappa_s$  for all  $t$  and  $s$ , provided initial wealth taxes or international transfers are chosen appropriately.

The proof of the lemma is in Appendix B. In proving this lemma, we use only the properties that any competitive equilibrium must satisfy and do not use any properties of the Ramsey allocation. The key idea is that a change in trade taxes, even if it is offsetting within a period, is neutral if the change in taxes is uniform across periods. Such a uniform change leaves after-tax relative prices unaffected and leaves allocations unaffected if international transfers and wealth taxes are adjusted appropriately. If the change is not uniform across periods, allocations will change.

This lemma helps in understanding our results on value-added taxes. Consider starting with a VAT without BA system in which trade taxes are zero and the VAT rates are set at the same level as in a VAT with BA system. If the VAT rates vary over time, the VAT without BA economy has dynamic production inefficiency. Adding trade taxes—which vary over time, as given in (51)—restores dynamic production efficiency to this economy. This restoration is possible only because trade taxes are not uniform over time.

These results shed light on some of those in the literature. For example, Barbiero et al. (2017) show that in an economy with sticky prices and no capital, permanent changes in tax systems similar to the ones studied here have no effects on allocations. This result is similar to our finding that uniform changes in trade taxes have no real effects. Barbiero et al. (2017) also show that anticipated changes in tax systems have real effects. This result is similar to our result that nonuniform changes in trade taxes may lead to changes in allocations. As another example, Costinot and Werning (2018) show that uniform changes in trade taxes have no effect on allocations.

We have shown that uniform changes in import tariffs and export subsidies leave domestic relative prices unaffected. We turn now to the question of the determination of the level of prices. If domestic prices are denominated in a world numeraire, as in our model, a uniform change in trade taxes of magnitude  $\kappa$  proportionately raises all domestic prices, so that  $\hat{p}_{11t} = \kappa p_{11t}$ ,  $\hat{q}_{1t} = \kappa q_{1t}$ ,  $\hat{w}_{1t} = \kappa w_{1t}$ . In Lemma 2 below, we show that if domestic prices are denominated in terms of a domestic numeraire, then a change in the exchange rate between the domestic and the world numeraires can achieve the needed adjustment without having to change domestic prices at all. We let tildes denote prices in terms of a domestic numeraire and  $E_t$  denote the exchange rate between the domestic and the world numeraire measured as units of domestic numeraire per world numeraire; for example,  $\tilde{p}_{11t} = E_t p_{11t}$ .

**Lemma 2 (Exchange rate adjustment):** Consider a competitive equilibrium of an arbitrary economy. Consider now an alternative economy with the same international prices in world numeraire— $Q_t$ ,  $p_{12t}$ ,  $p_{21t}$ —and the same domestic prices—in domestic currency,  $\tilde{q}_{1t}$ ,  $\tilde{p}_{11t}$ ,  $\tilde{w}_{1t}$ —in which allocations, domestic policies, and the exchange rate are denoted by carets. Suppose now policies in the alternative economy satisfy  $1 - \hat{\tau}_{12t}^x = \kappa(1 - \tau_{12t}^x)$  and  $1 + \hat{\tau}_{21t}^m = \kappa(1 + \tau_{21t}^m)$ . There is an equilibrium in the alternative economy, with the same allocations and domestic policies, and with exchange rates given by  $\hat{E}_t = E_t/\kappa$ , provided initial wealth taxes or international transfers are chosen appropriately.

Next we turn to the needed adjustment in the initial wealth taxes or international transfers. In order to understand the needed adjustment, suppose now that foreign assets, denominated in the world numeraire,  $f_{10}$ , are fixed. In Appendix B, we show that in this case, only the initial wealth tax may have to be adjusted. There is no need to adjust international

transfers to satisfy the balance of payments condition for country 1 in (14). If, instead, domestic and foreign assets of country 1,  $b_{10}$  and  $f_{10}$ , are denominated in the domestic numeraire, there is no need to adjust the initial wealth tax, but international transfers may need to be adjusted.

## IV Remarks on the Generality of the Results

In this section, we argue that our results generalize to other models of international trade and models of nonlinear taxation.

### *Other models of international trade*

Thus far we have concentrated on one widely used model of international trade—namely, that in Backus, Kehoe, and Kydland (1994). This focus allowed us to derive explicit expressions for the optimal wedges and allowed for a detailed analysis of alternative tax systems. Here, we show that our propositions continue to hold in two other widely used models of international trade.

Consider, for example, the economy in Stockman and Tesar (1995). This economy has two countries. Consumers in each country derive utility from a traded good produced in their country, a traded good produced in the other country, and a non-traded good. For simplicity, we consider a static version of their model. In this version, consumers' utility in, say, country 1 is given by

$$\frac{1}{1-\sigma} [(c_1^\theta c_2^{1-\theta})^\mu + d_1^\mu]^{\frac{1-\sigma}{\mu}} v(n_1),$$

where  $c_1$  is the consumption of the traded good produced in country 1,  $c_2$  is the consumption of the traded good produced in country 2, and  $d_1$  is the amount of non-traded good produced in country 1. The preferences in country 2 are described in a similar fashion. Goods are produced with a linear technology that uses labor. Mapping this economy into ours requires only adding for each country an intermediate good that captures the role of the non-traded good. To develop this map, consider a technology for producing the single final good given

by

$$C_1 = [(y_{11}^\theta y_{21}^{1-\theta})^\mu + d_1^\mu]^{\frac{1}{\mu}}.$$

with preferences given by

$$\frac{1}{1-\sigma} C_1^{1-\sigma} v(n_1),$$

and similarly for country 2. It is straightforward to show, with offsetting trade taxes, that proposition 2 holds for the reinterpreted Stockman-Tesar economy. Our other results also continue to hold.

Consider, next, a model with a continuum of goods on the interval  $[0, 1]$ , like the one in Obstfeld and Rogoff (1995).<sup>9</sup> Goods indexed  $[0, n]$  are produced in country 1, and the remaining goods are produced in country 2. We assume that these goods are produced by competitive firms. Preferences over the final consumption good,  $C_{it}$ , and labor,  $n_{it}$ , for residents of country  $i$  are given by

$$(52) \quad \sum_{t=0}^{\infty} \beta^t \left[ \frac{C_{it}^{1-\sigma}}{1-\sigma} - v(n_{it}) \right],$$

where

$$(53) \quad C_{it} = \left[ \int c_{it}(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}}.$$

Here,  $c_{it}(z)$  is consumption of good  $z$  in country  $i$ . Labor is the only input of production, and one unit of labor produces one unit of each of these goods, so that the technology for, say, country 1 is  $y_{1t}(z) = n_{1t}(z)$ ,  $z \in [0, n]$ , where  $y_{it}(z)$  is the amount of the good  $z$  produced in country  $i$  and  $n_{it}(z)$  is the labor used in the production of good  $z$  in country  $i$ , together with

$$n_{1t} = \int_0^n n_{1t}(z) dz.$$

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<sup>9</sup>Obstfeld and Rogoff (1995) have monopolistic competition and sticky prices. We consider a version of their model without these features.

The technology is defined in a similar way for country 2.

To map this economy into our setup, we need to extend our economy to allow for a continuum of traded intermediate goods. Let  $y_{ijt}(z)$  denote the intermediate good of type  $z$  produced in country  $i$  and used in country  $j$ . The technology for producing the single final non-traded consumption good is given for, say, country 1, by

$$(54) \quad C_{1t} = \left[ \int_0^n y_{11t}(z)^{\frac{\theta-1}{\theta}} dz + \int_n^1 y_{21t}(z)^{\frac{\theta-1}{\theta}} dz \right]^{\frac{\theta}{\theta-1}},$$

and similarly for country 2. The technology for producing these intermediate goods is the same as in Obstfeld and Rogoff (1995). Preferences are given by (52). It should be clear that all our propositions extend in a straightforward manner to this economy. A similar extension is possible for the economy in Eaton and Kortum (2002).

The logic behind these arguments suggests that our propositions also extend to other widely used models with perfect competition. Our results do not immediately generalize to trade models in which firms have monopoly power, such as those in Helpman and Krugman (1985) and Melitz (2003), or in which there are externalities, as in Alvarez, Buera, and Lucas (2013). These environments require corrective tax and subsidy instruments, even without the need to finance government expenditures with distorting taxes. We conjecture that with the appropriate tax and subsidy instruments, production efficiency is still optimal.

### ***Nonlinear taxation***

Here we briefly show how proposition 2 generalizes to environments with nonlinear taxation. We consider a Mirrlees-like environment in which we set up a mechanism design problem, then discuss how the resulting allocations can be implemented as a competitive equilibrium with nonlinear taxes on consumption and labor income and also trade taxes.

Consider a version of our benchmark model with a continuum of households in each country in the unit interval. Household  $k$  in country  $i$  is indexed by a parameter  $\theta_i^k$ . This parameter is constant over time and determines the effective units of labor supplied by household  $k$  in country  $i$ . Specifically, a household of type  $\theta_i^k$  that supplies  $n_t$  units of labor supplies  $l_t = \theta_i^k n_t$  units of effective labor. The distribution of household types is given by  $H_i(\theta_i^k)$ .



The cooperative planner observes consumption and effective labor by each household but not the household type. An allocation in this economy consists of allocations for each household  $\{c_t(\theta_i^k), l_t(\theta_i^k)\}$  and aggregate allocations for each country  $\{y_{ijt}, k_{it+1}, x_{it}\}$ . The resource constraints are the analogs of (2) and (3),

$$(55) \quad y_{i1t} + y_{i2t} = y_{it} = F^i \left( k_{it}, \int l_t(\theta_i^k) dH_i(\theta_i^k) \right),$$

$$(56) \quad \int c_t(\theta_i^k) dH_i(\theta_i^k) + g_{it} + x_{it} \leq G^i(y_{1it}, y_{2it}),$$

and (4). The utility of household of type  $\theta_i^k$  is given by

$$(57) \quad U^i(\theta_i^k) = \sum_{t=0}^{\infty} \beta^t \left[ u^i \left( c_t(\theta_i^k), \frac{l_t(\theta_i^k)}{\theta_i^k} \right) + h^i(g_{it}) \right].$$

An allocation is *incentive compatible* if

$$(58) \quad \sum_{t=0}^{\infty} \beta^t u^i(c_t(\theta_i^k), l_t(\theta_i^k)/\theta_i^k) \geq \sum_{t=0}^{\infty} \beta^t u^i(c_t(\hat{\theta}_i^k), l_t(\hat{\theta}_i^k)/\theta_i^k)$$

for all  $\theta_i^k, \hat{\theta}_i^k$ . An allocation is *incentive feasible* if it is incentive compatible and resource feasible in that it satisfies the resource constraints.

An allocation is a cooperative Mirrlees outcome if it maximizes

$$\omega^1 \int U^1(\theta_1^k) dJ_1(\theta_1^k) + \omega^2 \int U^2(\theta_2^k) dJ_2(\theta_2^k)$$

over the set of incentive feasible allocations, where  $J_i(\theta_i^k)$  is a distribution that represents a combination of the underlying distribution  $H$  and Pareto weights over households of different types.

Suppose now that the preferences of households are separable in that

$$(59) \quad u^i(c_t) - v \left( \frac{l_t}{\theta_i^k} \right).$$

It is straightforward to show that the Mirrleesian allocation can be supported as a competitive

equilibrium with nonlinear consumption and labor income taxes. Trade taxes may be needed to redistribute resources across countries as in proposition 2.

Using the same logic as that in Atkinson and Stiglitz (1976), Golosov, Kocherlakota, and Tsyvinski (2003), and Werning (2007), we have the following proposition, provided countries are connected through trade links.

**Proposition 9 (Production efficiency):** The Mirrleesian outcomes satisfy production efficiency so that free trade and unrestricted capital mobility are optimal.

In this formulation, workers differ from one another along a single dimension—namely, the parameter  $\theta_i^k$ , which determines the effective units of labor supplied by a worker. If they differ along multiple dimensions—say, because they differ in their comparative advantage in working in the various sectors—then the planning problem becomes a multidimensional screening problem and the analysis becomes more complicated. See Hosseini and Shourideh (2018) and Costinot and Werning (2018) for analyses of optimal trade taxation with restricted systems.

## V Concluding Remarks

We characterize cooperative Ramsey allocations in the global economy. We show that effective free trade and unrestricted capital mobility are optimal. In the benchmark model, Ramsey allocations can be supported by time-varying taxes on consumption and labor income. We study alternative implementations of the Ramsey allocation, including taxation of equity returns and foreign asset returns as well as corporate income. We show that it is optimal to tax all types of household assets at the same country-specific rate and not to tax corporate income. We show that border adjustments are desirable if in the benchmark model, it is optimal to have time-varying consumption taxes and trade taxes are not to be used. We clarify apparently conflicting views in the public finance and trade literatures regarding the desirability of border adjustments. We show that our results hold in a variety of trade models, and we extend our results to nonlinear tax systems.

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