Who benefits from international cooperation? The role of cross-country asymmetries

George Liontos[1] and Apostolis Philippopoulos[1,2]

[1]*Department of Economics, Athens University of Economics and Business, 76 Patission Street, Athens 10434, Greece*
[2]*CESifo, Munich, Germany*

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Abstract

We consider a two-country general equilibrium model, with capital mobility and fiscal policy. A well-established result is that, if national tax authorities commit themselves to future policies, international cooperation is superior to non-cooperative (Nash) fiscal policies. Nevertheless, cooperation can be counter-productive when there are other distortions in the background, like politically motivated governments, incomplete factor mobility, etc. We revisit the comparison between non-cooperative (Nash) and cooperative fiscal policies in the presence of cross-country asymmetries. We focus on cross-country asymmetries in public debt, institutional quality and TFP, which are considered to be among the striking differences between core and periphery EZ countries. In the presence of those asymmetries, policy cooperation increases welfare vis-á-vis competition, yet those benefits are distributed disproportionally, in the sense that the lion's share of gains from cooperation (welfare and output), go to the relatively disadvantaged economy. Actually, our results show that if asymmetries exceed a critical point, the leading economy may even lose from cooperation, facing strong incentives to act unilaterally. Moreover, a switch from a flexible to a rigid cooperative framework does not seem to reverse our findings. Putting all this together, we end up with a general second-best admission that in the presence of several distortions, taking just one out (here, lack of cooperation), is not necessarily productive. This may explain the difficulty of moving to fiscal unions with cooperative national fiscal policies in the presence of strong asymmetries across member countries.

Keywords: international cooperation, cross-country asymmetries

1 Introduction

In a world that becomes more integrated and countries increase their degree of engagement in competition phenomena, capital tax competition is an issue of high priority among researchers and policymakers. The dominant view is that tax competition tends to push capital tax rates into undesirably low levels, leading to significant capital flight, contraction of government revenues and under-provision of the public good. This kind of equilibrium *(Nash)* is self-defeating since, under the assumption of symmetric economies, cooperation in this typical prisoner's dilema problem is productive (i.e. it is preferable to non-cooperation). Also, note that cooperation can be counter-productive when there are other distortions in the background, like politically motivated governments (*Persson and Tabellini, 1995*[22]), incomplete factor mobility (*Perotti, 2001)*[21], etc. If we depart from the case of asymmetry results are not so straightforward. As it will become clear later, not all participants have incentives to cooperate, since benefits are not equally distributed.

The purpose of this paper is to reassess the fundamental assumptions of international economics on policy coordination and shed light on the role of cross-country asymmetries and how these asymmetries affect some established results in the literature of policy cooperation. In other words, we revisit the comparison between non-cooperative (Nash) and cooperative fiscal policies in the presence of cross-country asymmetries. From the point of view of a Ramsey (benevolent) policy maker, cooperative policies between symmetric countries are superior to Nash. Our study confirms this result, however, we differentiate to most of the related literature, by introducing asymmetries in our model. We focus on cross-country asymmetries in public debt, institutional quality and TFP, which are considered to be among the striking differences between core and periphery Euro-zone countries, especially after the 2008 crisis (*see e.g. Micossi, 2016*[20]) and the data presented in *Section 5.* Indeed, government debt as percentage of GDP rose dramatically in the periphery after the crisis. Moreover, twenty years after the inception of the Euro, the total factor productivity gap between the core and the periphery of Euro-zone is still present. In the field of institutions, property rights in the periphery economies are weakly protected, profits and returns may well be expropriated, the legal framework malfunctions and the cost of bureaucracy and political corruption impedes the starting of a company.

Hence, taking as given the structural differences between the core and the periphery, we wonder if international cooperation is productive at aggregate level. If it is, is it Pareto efficient? That is, does it benefit all types of countries? Or, there are winners and losers?

We consider a conventional neoclassical world economy model with two countries, where consumers value government consumption. For simplicity, we solve the model in a two-period time horizon as in *Persson and Tabellini (1992)*[23], *Kammas and Philippopoulos (2009)*[14] and many others. Our version allows for a fully logarithmic utility function and elastic labour supply, sacrificing tractability over flexibility. There is one single traded good and purchasing power parity *(PPP)* holds. In each country there is a representative household, a firm and a government. The household chooses consumption, leisure and savings in the form of domestic capital, domestic government bonds and foreign assets/liabilities to solve a standard utility max problem. The firm chooses capital and labor services to solve a standard profit max problem. The government taxes labor, domestic capital and capital invested at home from foreigners (*residence-based taxation*) and also issues bonds to finance utility-enhancing public expenditures. Capital is perfectly mobile between countries, while labour is not. The cross-country spillover stems out of the international capital mobility and leads to the well-know tax competition effect. We focus on the optimally chosen cooperative and non-cooperative fiscal policies.

We assume that governments in each country behave as Ramsey planners, choosing their tax policy at the beginning of the time horizon, whether they act cooperatively or non-cooperatively. Then, having observed policy selection, private agents make their decisions competitively and markets clear. Cooperation can now be *"flexible"* or *"rigid" (Alesina et al 2005)*[1]. A flexible union supports policy coordination across member states, attributing *country-specific* policy targets. On the other hand, a rigid union centralizes fiscal policy by imposing a *"one-size-fits-all"* cooperatively chosen policy applied to all countries (like common tariff policy, tax harmonization, a single currency, etc.). Notice that in the case of cooperation the social welfare

function is the weighted average of the welfare of the household in each country with equal weights given to each country.

As a baseline case, we derive numerical solutions of the symmetric model and then we introduce asymmetries. In terms of welfare, the model predicts that in the symmetric case, cooperative are superior to Nash strategies. The idea is that low tax rates may harm the provision of the public good, but they are good for investment and future consumption. On the other hand, the cooperative solution contributes more to the public good, however, higher capital tax rates discourage investors and consumers. This is already shown in *Mendoza and Tesar (2005)*[19].

However, when we allow for asymmetries in public debt, institutional quality and TFP, results change substantially. We find that if countries differ in initial debt-to-GDP ratio, cooperation (both flexible and rigid, but especially the latter) serves mainly the needs of high-debt countries. In the case of institutional quality asymmetries, cooperation, and especially rigid cooperation, is too restrictive for a country with weak institutions, as it leads to excessively high tax rates. If countries differ in TFP, flexible cooperation can benefit both countries and especially the one with low TFP (it allows for lower tax rates in the low TFP country than in the high TFP country), while, rigid cooperation is too restrictive for a country with low TFP. Putting all this together we end up with a second-best admission that when several distortions are present, taking just one out (here, lack of cooperation) is not necessary productive.

2 Literature

Capital tax competition has raised cause for concerns in EU policy circles for a long time. Both *OECD (1998)*[28] and *European Commission (2001)* consider tax competition a harmful practice that needs to be restrained. In fact, it is hard to collect taxes on income from abroad, so governments instead should tax capital income at the source to generate sufficient revenues. Moreover, if capital is mobile across countries, taxing capital income would lead to capital flight. Given that tax authorities do not share information to tax foreign-source income, capital tax policy will trigger tax competition for capital inflows. Thus, tax competition tends to squeeze capital taxes below the efficient level, resulting in reduced government revenues and under-provision of the public good.

Zodrow and Mieszkowski (1986)[30] implement a model with identical tax authorities to show that competition for mobile capital leads to reduced tax rates, compared to a closed-economy setting. Assuming that there is an increase in the domestic capital tax rate, the domestic net rate of return on capital decreases, leading to capital outflow. The foreign capital tax-bases would grow, and foreign tax revenues would rise, triggering a positive externality. This implies that capital tax rates, which are set under integrated capital markets, would be lower compared to the case of capital immobility.

Cooper (1988)[7] is concerned with strategic complementarity in agents' payoff functions and shows how these complementarities and spillovers may lead to coordination failures, such as multiple, Pareto-ranked equilibria and a multiplier process associated with changes in exogenous variables.

Bucovetsky and Wilson (1991)[4] stress out the importance of opening a region's borders to capital flows. Their model also incorporates a wage tax and shows that smaller economies choose to impose a zero-capital tax rate, given that income can only be taxed at the source. Nevertheless, the well-known problem of the under-provision of the public good is also present at their work.

Correia (1996)[8] shows that in a small open economy framework, where only source-based capital taxes are available, and the net world interest rate is exogenous and invariant, capital variations do not alter drastically the optimal tax path of the closed economy. When perfect capital mobility is introduced, the optimal choice of capital taxes does not change substantially. However, the optimal decisions in the open economy (e.g. *Razin and Sadka (1991)[26]*) almost coincide to the closed economy solution (*Feldstein (1978)*[11]), when the system of taxation is the worldwide, and change significantly when the territorial system is used.

Lejour and Verbon (1997)[17] and *Koethenbuerger and Lockwood (2010)*[16] assume the existence of a negative cross-border tax externality because of a preference on the part of households for portfolio diversification. Their model setup does not include intertemporal externality and in fact, if the assumption of a preference for diversification is removed, the standard "race-to-the bottom" result arises. In addition to this, both *Lejour and Verbon (1997)* and *Koethenbuerger and Lockwood (2010)* assume only balanced growth paths, as well as a savings rate which is independent of the rate of return on capital.

Persson and Tabellini (2000)[24] prove that tax competition between two symmetric countries results in inefficiently low capital tax rates, with negative consequences on global welfare. The distortion is greater the more mobile is capital. Perfect capital mobility implies zero tax rates on capital and both countries tax only labour.

According to *Wildasin (2003)*[29], capital tax rate decreases with the mobility of capital, confirming the traditional view. The model describes a small open economy where the adjustment of capital inputs comes at an adjustment cost, the net world interest rate is exogenous, capital taxes are time-invariant and there are also lump-sum taxes.

Mendoza and Tesar (2005) observe that the integration of European financial markets in the 1980s allowed capital to move almost-freely across countries with harmonized indirect taxes, but largely differentiated factor taxes. The years that followed, capital tax competition provided ambiguous results on whether a "race to the bottom" took place. Specifically, the UK lowered its capital tax to a rate closer to those of France, Germany and Italy, while capital taxes changed slightly in these countries. *Mendoza and Tesar* utilize a Neoclassical growth model of tax competition, with the basic international externalities of tax policy, that is in line with the facts of the aforementioned period.

Klein et al. (2005)[15] and *Quadrini (2005)*[25] incorporate limited commitment of tax policy in a fully dynamic open economy model of optimal taxation. Their analysis is limited at the steady state of asymmetric countries and how this is affected using capital and labour taxes. *Quadrini (2005)* introduces capital mobility and shows that there is a sudden decrease in capital tax rates. *Kammas and Philippopoulos (2009)*, provide a quantitative assessment of the welfare benefit of international tax policy coordination. They find that in a world economy with international capital mobility and international public goods, the welfare gains from cooperation can be really big, although in the absence of international public goods the quantitative difference of cooperative and non-cooperative case is negligible.

Gross (2014)[12] studies large open economies and finds that in the long-run capital tax rates are zero, a result which was established in *Chamley (1986)*[5] and *Judd (1985)*[13]. This outcome is robust whether the jurisdictions set their policy cooperatively or not, and is independent of the degree of capital mobility, the number of countries, or a country's size relative to the rest of the world.

Klein et al. (2017) focus on the same model as *Gross (2014)* and they extend their analysis not only on the long-run equilibrium, but also on the transition to the steady state. They solve an optimal taxation problem under commitment, treating the other government's policies as given. Numerically, source-based capital taxes are initially positive and slowly decline towards zero.

Chari et al. (2018)[6] study alternative setups of the Ramsey allocation including residence-based taxation of equity returns, foreign asset returns and firms profits. They also consider value-added taxes with and without border adjustments and argue that, given standard preferences, free trade is optimal in the second best allocation and capital tax should be zero in the steady state. Also, they find no evidence that capital should be taxed along the transition.

The literature on property rights protection dates back to the classic work of *Tullock (1967)[27]* and has since been enriched with numerous studies. We consider the work of *Economides, Park, Philippopoulos (2007)*[10], *Economides, Kalyvitis, Philippopoulos (2008)*[9], *Angelopoulos, Philippopoulos, Vassilatos (2009)*[3], *Angelopoulos, Economides, Vassilatos (2011)*[2].

3 World Economy - The Model

We use a conventional neoclassical world economy model with two countries. For simplicity, as in *Persson and Tabellini (1992, 1995, 2000)*, we assume a two-period time horizon and a fixed number of identical agents in each country. Also, we assume that:

i. There are two separate national governments, one in each country, that act as benevolent Ramsey planners, who commit to their future policy and maximise their households' utility function,
ii. They employ three policy instruments, tax on labour, tax on domestic capital and capital invested at home from foreigners, tax on labour and one-period government bonds, to finance utility-enhancing public expenditures,
iii. Domestic and foreign investors are taxed at the same rate, following the residence principle of taxation,
iv. Private agents of each country consume at home and invest at home and abroad.

Sequence of Events
In the beginning of the time horizon, governments choose their tax policies, either non-cooperatively or cooperatively, under commitment (*Ramsey-type policy*). In turn, having observed policy selection, private agents act competitively and choose their consumption, leisure and savings in the form of domestic and foreign capital. Also, all markets clear. To derive the Decentralized Equilibrium for any feasible tax policy, we solve the above problems by backward induction, taking prices and policies as given. Next, we solve for Nash national tax policies, in the sense that each government chooses its own tax rates optimally, subject to the DE and taking as given the policies of the other government. Finally, we solve for cooperative policies, assuming that countries choose their policy jointly. Our model is a richer version of the model used by *Persson and Tabellini (1992)* and many others since then.

3.1 Households

In each period, we assume there is a fixed number of identical households in both countries. For simplicity, we set the population size N equal to 1 in each country. The objective of the household in country i is to maximise its utility[1]:

$$\sum_{t=1}^{2} \beta^{t-1} u(c_{i,t}, l_{i,t}) \tag{1}$$

where $\beta \in (0,1)$ is the time preference rate.

The utility function is assumed to be log-linear, of the following form:

$$\begin{aligned} U^{(i)} =& \mu_1 \log c_{i,1} + \mu_2 \log(1 - l_{i,1}) + \mu_3 \log g_{i,1} \\ &+ \beta \Big\{ \mu_1 \log c_{i,2} + \mu_2 \log(1 - l_{i,2}) + \mu_3 \log g_{i,2} \Big\} \end{aligned} \tag{2}$$

where $g_{i,t}$ is the total government consumption that offers direct utility to households and μ_1, μ_2, μ_3 are the weights given to consumption, leisure and public good respectively. The household is endowed with one unit of time in each period, $t = 1, 2$, and divides it between work effort, $h_{i,t}$, and leisure, $l_{i,t}$. Thus, the time constraint in each period is $h_{i,t} + l_{i,t} = 1$. Furthermore, as in *Angelopoulos et al. (2011)*, we assume that it further divides its labour time in the second period between productive work $s_{i,2} l_{i,2}$ and rent-extracting activities $(1 - s_{i,2}) l_{i,2}$, where $0 < s_{i,2} \leq 1$ and $0 \leq (1 - s_{i,2}) < 1$ denote the fractions of non-leisure time that the household allocates to productive work and rent extraction[2]. Each household consumes, $c_{i,t}$, saves in the form of capital invested at home, $k_{i,2}$, capital invested abroad, $f_{i,2}$, and one-period government bonds,

[1] $-i$ denotes country's i foreign counterpart.

[2] In order to study the impact of weak property rights on savings, we assume that rent extraction takes places only in second period. Adding rent extraction also in period 1 does not make any qualitative difference.

$b_{i,2}$. It receives labour income, $w_{i,t}l_{i,t}$, capital income from investing at home, $r_{i,t}k_{i,t}$, capital income from investing abroad, $r_{-i,t}f_{i,2}$ in the second period only, and interest income from bonds, $r^b_{i,t}b_{i,t}$, where $w_{i,t}$ is the wage rate, $r_{i,t}$ is the return to capital invested at home, $r_{-i,t}$ is the return on capital invested abroad and $r^b_{i,t}$ is the return to government bonds. We also assume that the households are also firm owners and receive profits, $\Pi_{i,t}$. The budget constraints in the two periods are

$$c_{i,1} + k_{i,2} + b_{i,2} + f_{i,2} = (1 + (1 - \tau^k_{i,1})r_{i,1} - \delta)k_{i,1} + (1 - \tau^l_{i,1})w_{i,1}l_{i,1} + (1 + r^b_{i,1})b_{i,1} \tag{3}$$

$$\begin{aligned} c_{i,2} = {} & (1 + (1 - \tau^k_{i,2})r_{i,2} - \delta)k_{i,2} + (1 - \tau^l_{i,2})w_{i,2}s_{i,2}l_{i,2} + (1 + r^b_{i,2})b_{i,2} + \Pi_{i,2} \\ & + (1 + (1 - \tau^k_{-i,2})r_{-i,2} - \delta)f_{i,2} - m\frac{f^2_{i,2}}{2} + \frac{(1 - s_{i,2})l_{i,2}}{\sum^N_{j=1}(1 - s^j_{i,2})l^j_{i,2}}\Theta_i Y_{i,2} \end{aligned} \tag{4}$$

where $0 \leq \tau^i_{k,t}, \tau^{-i}_{k,t} < 1$ is the tax rate on capital income on home and abroad respectively, and $0 \leq \tau^i_{l,t} < 1$ is the tax rate on labour income. Parameters $0 \leq \delta \leq 1$ and $m \in [0, +\infty)$ capture the depreciation rate of private capital and the mobility cost of capital invested abroad, respectively. $0 \leq \Theta_i < 1$ is the economy-wide degree of rent extraction and higher values of this parameter imply weaker protection of property rights. The last term of equation (4) denotes a contestable prize available due to poor institutions. Each consumer aims to grab a fraction of that prize which depends on the extractive effort she puts relative to the extractive efforts put by all individuals.

The household in each country i chooses allocations $\{c_{i,1}, c_{i,2}, l_{i,1}, l_{i,2}, s_{i,2}, k_{i,2}, f_{i,2}, b_{i,2}\}$ to maximise (2), subject to constraints (3)–(4), initial conditions for $k_{i,1}, b_{i,1}$ and no-arbitrage conditions $k_{i,3} \equiv f_{i,3} \equiv b_{i,3} \equiv 0$. In doing so, it acts competitively by taking prices and policy variables as given.

The first-order conditions are

$$\frac{\mu_1}{c_{i,1}}(1 - \tau^l_{i,1})w_{i,1} = \frac{\mu_2}{1 - l_{i,1}} \tag{5}$$

$$\frac{\mu_1}{c_{i,2}}\Big\{(1 - \tau^l_{i,2})w_{i,2}s_{i,2} + \frac{(1 - s_{i,2})}{\sum^N_{j=1}(1 - s^j_{i,2})l^j_{i,2}}\Theta_i Y_{i,2}\Big\} = \frac{\mu_2}{1 - l_{i,2}} \tag{6}$$

$$(1-\tau^l_{i,2})w_{i,2}l_{i,2} = \frac{l_{i,2}}{\sum^N_{j=1}(1 - s^j_{i,2})l^j_{i,2}}\Theta_i Y_{i,2} \tag{7}$$

$$c_{i,2} = \beta\Big\{1 + (1 - \tau^k_{i,2})r_{i,2} - \delta\Big\}c_{i,1} \tag{8}$$

$$c_{i,2} = \beta\Big\{1 + r^b_{i,2}\Big\}c_{i,1} \tag{9}$$

$$c_{i,2} = \beta\Big\{1 + (1 - \tau^k_{-i,2})r_{-i,2} - \delta - mf_{i,2}\Big\}c_{i,1} \tag{10}$$

and the constraints. Conditions (4),(5) denote leisure-consumption trade off in periods 1 & 2 and equate the marginal value of labour to the after-tax return to labour, condition (7) is the optimality condition with respect to the productive time, $s_{i,2}$ and conditions (8),(9),(10) are the standard Euler conditions for domestic capital, $k_{i,2}$, bonds, $b_{i,2}$, and foreign capital, $f_{i,2}$.

3.2 Firms

In each period there is a fixed number of firms(for simplicity, the number of firms equals the number of households, i.e. N=1). Each firm produces a homogeneous product, $Y_{i,t}$, by using capital, $K^F_{i,t}$, and labour services, $L^F_{i,t}$. The firm's production function is Cobb-Douglas:

$$Y^F_{i,t} = A(K^F_{i,t})^\alpha (L^F_{i,t})^{1-\alpha} \tag{11}$$

where $\alpha \in (0, 1)$ is the output elasticity of capital invested at home, and A is total factor productivity. We assume constant returns to scale. In period 1 each firm chooses capital and labour services to solve a

standard profit maximization problem:

$$\max_{K^F_{i,1},L^F_{i,1}} \Pi^F_{i,1} = Y^F_{i,1} - r_{i,1}K^F_{i,1} - w_{i,1}L^F_{i,1} \qquad s.t. \qquad Y^F_{i,1} = A(K^F_{i,1})^{\alpha}(L^F_{i,1})^{1-\alpha}$$

The first-order conditions are:

$$\alpha\frac{Y^F_{i,1}}{K^F_{i,1}} = r_{i,1} \tag{12}$$

$$(1-\alpha)\frac{Y^F_{i,1}}{L^F_{i,1}} = w_{i,1} \tag{13}$$

However, in the second-period firms can keep a fraction only, $0 < 1-\Theta_i \leq 1$, of their output produced, $Y^F_{i,2}$, while the rest, $\Theta_i Y^F_{i,2}$, is expropriated by households who compete with other for a share of this contestable prize in a *Tullock-type*[27] redistributive struggle. The also employ domestic capital and capital invested at home by foreigners, as well as, private effective labour. The profit function is now

$$\Pi^F_{i,2} = (1-\Theta_i)Y^F_{i,2} - r_{i,2}K^F_{i,2} - w_{i,2}L^F_{i,2} \tag{14}$$

The first-order conditions are

$$(1-\Theta_i)\alpha\frac{Y^F_{i,2}}{K^F_{i,2}} = r_{i,2} \tag{15}$$

$$(1-\Theta_i)(1-\alpha)\frac{Y^F_{i,2}}{L^F_{i,2}} = w_{i,2} \tag{16}$$

3.3 Public Sector

The government taxes effective labour, domestic capital and capital invested at home from foreigners (*residence-based taxation*) at rates $0 \leq \tau^l_{i,t} < 1$ and $0 \leq \tau^k_{i,t} < 1$ respectively, and also issues bonds to finance utility-enhancing public expenditures. The within-period government budget constraints are:

$$g_{i,1} + (1+r^b_{i,1})b_{i,1} = Y_{i,1}\{\alpha\tau^k_{i,1} + (1-\alpha)\tau^l_{i,1}\} \tag{17}$$

$$g_{i,2} + (1+r^b_{i,2})b_{i,2} = (1-\Theta_i)Y_{i,2}\{\alpha\tau^k_{i,2} + (1-\alpha)\tau^l_{i,2}\} \tag{18}$$

where $g_{i,1}$ and $g_{i,2}$ account for total government spending, and $b_{i,1}$ and $b_{i,2}$ are the government bonds issued at periods 1 & 2 respectively.

3.4 Decentralized Equilibrium

We solve for a decentralized competitive equilibrium (DCE) in which

i. households in both countries maximise their welfare,
ii. firms maximise profits,
iii. all constraints are satisfied and
iv. all markets clear.

Net returns are defined as

$$R_{i,t} \equiv (1-\tau^k_{i,t})r_{i,t} - \delta \tag{19}$$

$$W_{i,t} \equiv (1-\tau^l_{i,t})w_{i,t} \tag{20}$$

In equilibrium, the total capital demanded by firms is equal to the sum of the private capital and the Foreign Direct Investment supplied by the households, in each country. This implies

$$K_{i,1}^F \equiv K_{i,1} \equiv k_{i,1}, \qquad K_{i,2}^F \equiv K_{i,2} \equiv k_{i,2} + f_{-i,2} \tag{21}$$

The equilibrium in labour markets implies that demand equals supply

$$L_{i,1}^F \equiv L_{i,1} \equiv l_{i,1}, \qquad L_{i,2}^F \equiv L_{i,2} \equiv s_{i,2} l_{i,2} \tag{22}$$

The Decentralized Equilibrium is comprised by the following set of equations for each country

$$c_{i,1} + k_{i,2} - (1-\delta)k_{i,1} + f_{i,2} + g_{i,1} = y_{i,1} \tag{23}$$

$$c_{i,2} - (1-\delta)k_{i,2} + g_{i,2} = y_{i,2} + (1-\tau_{i,2}^k) r_{i,2} f_{-i,2} + \{1 + (1-\tau_{-i,2}^k) - \delta\} f_{i,2} - m\frac{f_{i,2}^2}{2} \tag{24}$$

$$\frac{\mu_1}{c_{i,1}}(1-\tau_{i,1}^l) w_{i,1} = \frac{\mu_2}{1-l_{i,1}} \tag{25}$$

$$\frac{c_{i,2}}{1-l_{i,2}} = \frac{\mu_1}{\mu_2}\Big\{(1-\tau_{i,2}^l)(1-\Theta_i)(1-\alpha) + \Theta_i\Big\}\frac{y_{i,2}}{l_{i,2}} \tag{26}$$

$$s_{i,2} = \frac{(1-\tau_{i,2}^l)(1-\Theta_i)(1-\alpha)}{\Theta_i + (1-\tau_{i,2}^l)(1-\Theta_i)(1-\alpha)} \tag{27}$$

$$c_{i,2} = \beta\Big\{1 + (1-\tau_{i,2}^k) r_{i,2} - \delta\Big\} c_{i,1} \tag{28}$$

$$c_{i,2} = \beta\Big\{1 + (1-\tau_{-i,2}^k) r_{-i,2} - \delta - m f_{i,2}\Big\} c_{i,1} \tag{29}$$

$$g_{i,1} + (1 + (1-\tau_{i,1}^k) r_{i,1} - \delta) b_{i,1} = y_{i,1}(\alpha\tau_{i,1}^k + (1-\alpha)\tau_{i,1}^l) + b_{i,2} \tag{30}$$

$$g_{i,2} + (1 + (1-\tau_{i,2}^k) r_{i,2} - \delta) b_{i,2} = (1-\Theta_i) y_{i,2}(\alpha\tau_{i,2}^k + (1-\alpha)\tau_{i,2}^l) \tag{31}$$

where

$$y_{i,1} = A k_{i,1}^{\alpha} l_{i,1}^{1-\alpha}, \qquad r_{i,1} = \alpha\frac{y_{i,1}}{k_{i,1}}$$

$$y_{i,2} = A(k_{i,2} + f_{-i,2})^{\alpha}(l_{i,2} s_{i,2})^{1-\alpha}, \qquad r_{i,2} = \alpha\frac{y_{i,2}}{k_{i,2} + f_{-i,2}}$$

$$w_{i,1} = (1-\alpha)\frac{y_{i,1}}{l_{i,1}}, \qquad r_{i,1}^b = (1-\tau_{i,1}^k) r_{i,1} - \delta$$

$$w_{i,2} = (1-\alpha)\frac{y_{i,2}}{l_{i,2} s_{i,2}} \qquad r_{i,2}^b = (1-\tau_{i,2}^k) r_{i,2} - \delta$$

where i denotes home country and $-i$ its foreign counterpart.

System of unknowns

We have a system of 18 equations in

1. Allocations $\{c_{i,1}, c_{i,2}, c_{-i,1}, c_{-i,2}, k_{i,2}, k_{-i,2}, l_{i,1}, l_{i,2}, l_{-i,1}, l_{-i,2}, s_{i,2}, s_{-i,2}, f_{i,2}, f_{-i,2}\}$
2. Policies $\{b_{i,2}, b_{-i,2}, g_{i,2}, g_{-i,2}\}$

for any feasible policy $\{\tau_{i,1}^k, \tau_{i,2}^k, \tau_{-i,1}^k, \tau_{-i,2}^k, \tau_{i,1}^l, \tau_{i,2}^l, \tau_{-i,1}^l, \tau_{-i,2}^l, g_{i,1}, g_{-i,1}\}$

4 Optimal policy and allocations in a symmetric equilibrium

We will focus on policies with commitment or what is known as Ramsey policy[18][3]. This means the policies are chosen once-and-for-all at the beginning of time horizon. Within this context, we will solve for cooperative and Nash Ramsey-type policies. A usual technical detail in optimal taxation literature is that, most of the times, we cannot derive an indirect utility function, that is, we cannot write the utility function of the government as a function of the policy instruments only *(Chamley, 1986)*. To overcome this technicality we formulate the problem so as each government chooses the endogenous variables of the DE, subject to the equations consisting the DE. This is the so-called dual approach to the Ramsey problem.

4.1 Non-cooperative policies

As it is standard in the optimal taxation literature, the government moves first and announces its tax schedule, whereupon private agents react to this. The world economy consists of domestic and foreign households, which are affected by domestic policies. Agents in both countries act simultaneously. The two governments announce their tax schedules at the same time. Specifically, they choose independently their bond issues, $b_{i,2}, b_{-i,2}$, capital tax rates, $\tau^k_{i,2}, \tau^k_{-i,2}$, labour tax rates, $\tau^l_{i,1}, \tau^l_{i,2}, \tau^l_{-i,1}, \tau^l_{-i,2}$ and government spending in period $t = 2$, $g_{i,2}, g_{-i,2}$. Notice that first-period capital tax rate $\tau^k_{i,1} \equiv \tau^k_{-i,1}$ is set to 0.2 and government spending, $g_{i,1}$,$g_{-i,1}$, is set at 20% of output.

The governments consider the households' choice variables as control variables when they incorporate the optimality conditions and budget constraints of the households. We therefore, reformulate the government's problem as a social planner's function, subject to the set of constraints comprising the DE. Additionally, prices, r and w are equal to their marginal products, taking into account firms' profit maximization in both countries. We define equilibrium policies assuming that each government takes the equilibrium policies of the other government as given.

The government in country i maximises

$$\begin{aligned} U^{(i)} =& \mu_1 \log c_{i,1} + \mu_2 \log(1 - l_{i,1}) + \mu_3 \log g_{i,1} \\ &+ \beta\Big\{\mu_1 \log c_{i,2} + \mu_2 \log(1 - l_{i,2}) + \mu_3 \log g_{i,2}\Big\} \end{aligned} \tag{32}$$

subject to the DE equations (24)–(32).

The set of control variables is

$$\{c_{i,1}, c_{i,2}, c_{-i,1}, c_{-i,2}, l_{i,1}, l_{i,2}, l_{-i,1}, l_{-i,2}, s_{i,2}, s_{-i,2}, k_{i,2}, k_{-i,2}, f_{i,2}, f_{-i,2}, b_{i,2}, b_{-i,2}, g_{i,2}, g_{-i,2}, \tau^k_{i,2}, \tau^l_{i,1}, \tau^l_{i,2}\}$$

The non-cooperative equilibrium consists of two separate optimization problems, one for each country. The government in country $-i$ solves an identical problem and chooses all the endogenous variables of the DE and its own policy instruments. The optimal policy for each government is defined when it chooses the best action that is admissible for any belief of what the other government does:

Definition 1 (Best response function). A best response function is a feasible policy that maximises the agent's utility for each belief of foreign policy.

Definition 2 (Pure-strategy equilibrium). A pure-strategy open-economy equilibrium is a sequence of prices $\{R_{i,2}, R_{-i,2}, W_{i,t}, W_{-i,t}\}^2_{t=1}$, government policies $\{\tau^k_{i,2}, \tau^k_{-i,2}, \tau^l_{i,t}, \tau^l_{-i,t}\}^2_{t=1}$, and allocations $\{c_{i,t}, c_{-i,t}, l_{i,t}, l_{-i,t}, s_{i,2}, s_{-i,2}, k_{i,2}, k_{-i,2}, f_{i,2}, f_{-i,2}, b_{i,2}, b_{-i,2}\}^2_{t=1}$, out of a set of equilibrium strategies and private agents decisions such that:

[3] see Ljungqvist and Sargent (2004, chapter 15), for a review of the Ramsey tax policy problem.

1. the equilibrium strategy of each government is an optimal response to the other government's equilibrium strategy;

2. agents in both countries maximise their utility subject to their budget constraints, taking as given prices and taxes

3. firms in both countries maximise profits, taking prices as given.

Finally, the Nash equilibrium system is explained by 24 equations in 24 unknowns. Allocations, $\{c_{i,1}, c_{i,2}, c_{-i,1}, c_{-i,2}, l_{i,1}, l_{i,2}, l_{-i,1}, l_{-i,2}, s_{i,2}, s_{-i,2}, k_{i,2}, k_{-i,2}, f_{i,2}, f_{-i,2}, b_{i,2}, b_{-i,2}, g_{i,2}, g_{-i,2}\}$ and policies, $\{\tau^k_{i,2}, \tau^l_{i,1}, \tau^l_{i,2}, \tau^k_{-i,2}, \tau^l_{-i,1}, \tau^l_{-i,2}\}$.

We form the Lagrangian function of the domestic government as follows

$$
\begin{aligned}
L = U^{(i)} &+ \lambda_1\Big\{c_{i,1} + k_{i,2} - (1-\delta)k_{i,1} + f_{i,2} + g_{i,1} - y_{i,1}\Big\} \\
&\lambda_2\Big\{c_{i,2} - (1-\delta)k_{i,2} + g_{i,2} - y_{i,2} - (1-\tau^k_{i,2})r_{i,2}f_{-i,2} - \{1 + (1-\tau^k_{-i,2}) - \delta\}f_{i,2} + m\frac{f^2_{i,2}}{2}\Big\} \\
&\lambda_3\Big\{\frac{\mu_1}{c_{i,1}}(1-\tau^l_{i,1})w_{i,1} - \frac{\mu_2}{1-l_{i,1}}\Big\} \\
&\lambda_4\Big\{\frac{c_{i,2}}{1-l_{i,2}} - \frac{\mu_1}{\mu_2}\{(1-\tau^l_{i,2})(1-\Theta_i)(1-\alpha) + \Theta_i\}\frac{y_{i,2}}{l_{i,2}}\Big\} \\
&\lambda_5\Big\{s_{i,2} - \frac{(1-\tau^l_{i,2})(1-\Theta_i)(1-\alpha)}{\Theta_i + (1-\tau^l_{i,2})(1-\Theta_i)(1-\alpha)}\Big\} \\
&\lambda_6\Big\{c_{i,2} - \beta\Big\{1 + (1-\tau^k_{i,2})r_{i,2} - \delta\Big\}c_{i,1}\Big\} \\
&\lambda_7\Big\{c_{i,2} - \beta\Big\{1 + (1-\tau^k_{-i,2})r_{-i,2} - \delta - mf_{i,2}\Big\}c_{i,1}\Big\} \\
&\lambda_8\Big\{g_{i,1} + (1 + (1-\tau^k_{i,1})r_{i,1} - \delta)b_{i,1} - y_{i,1}(\alpha\tau^k_{i,1} + (1-\alpha)\tau^l_{i,1}) - b_{i,2}\Big\} \\
&\lambda_9\Big\{g_{i,2} + (1 + (1-\tau^k_{i,2})r_{i,2} - \delta)b_{i,2} - (1-\Theta_i)y_{i,2}(\alpha\tau^k_{i,2} + (1-\alpha)\tau^l_{i,2})\Big\} \qquad (33)
\end{aligned}
$$

$$
\begin{aligned}
&\lambda_{10}\Big\{c_{-i,1} + k_{-i,2} - (1-\delta)k_{-i,1} + f_{-i,2} + g_{-i,1} - y_{-i,1}\Big\} \\
&\lambda_{11}\Big\{c_{-i,2} - (1-\delta)k_{-i,2} + g_{-i,2} - y_{-i,2} - (1-\tau^k_{-i,2})r_{-i,2}f_{i,2} - \{1 + (1-\tau^k_{i,2}) - \delta\}f_{-i,2} + m\frac{f^2_{-i,2}}{2}\Big\} \\
&\lambda_{12}\Big\{\frac{\mu_1}{c_{-i,1}}(1-\tau^l_{-i,1})w_{-i,1} - \frac{\mu_2}{1-l_{-i,1}}\Big\} \\
&\lambda_{13}\Big\{\frac{c_{-i,2}}{1-l_{-i,2}} - \frac{\mu_1}{\mu_2}\{(1-\tau^l_{-i,2})(1-\Theta_{-i})(1-\alpha) + \Theta_{-i}\}\frac{y_{-i,2}}{l_{-i,2}}\Big\} \\
&\lambda_{14}\Big\{s_{-i,2} - \frac{(1-\tau^l_{-i,2})(1-\Theta_{-i})(1-\alpha)}{\Theta_{-i} + (1-\tau^l_{-i,2})(1-\Theta_{-i})(1-\alpha)}\Big\} \\
&\lambda_{15}\Big\{c_{-i,2} - \beta\Big\{1 + (1-\tau^k_{-i,2})r_{-i,2} - \delta\Big\}c_{-i,1}\Big\} \\
&\lambda_{16}\Big\{c_{-i,2} - \beta\Big\{1 + (1-\tau^k_{i,2})r_{i,2} - \delta - mf_{-i,2}\Big\}c_{-i,1}\Big\} \\
&\lambda_{17}\Big\{g_{-i,1} + (1 + (1-\tau^k_{-i,1})r_{-i,1} - \delta)b_{-i,1} - y_{-i,1}(\alpha\tau^k_{-i,1} + (1-\alpha)\tau^l_{-i,1}) - b_{-i,2}\Big\} \\
&\lambda_{18}\Big\{g_{-i,2} + (1 + (1-\tau^k_{-i,2})r_{-i,2} - \delta)b_{-i,2} - (1-\Theta_{-i})y_{-i,2}(\alpha\tau^k_{-i,2} + (1-\alpha)\tau^l_{-i,2})\Big\}
\end{aligned}
$$

4.2 Cooperative policies

With capital mobility in a non-cooperative equilibrium, governments face limited capacity to capture the rents accruing to the initial capital stock, due to possible capital flight. This problem can be alleviated if governments cooperate. Suppose now that governments are members of a union and coordinate their actions, or equivalently, there is a Ramsey planner who maximises a social welfare function which is the weighted average of the welfare of the household in each country with equal weights given to each country.

$$W^{coop} = \gamma U^{(i)} + (1-\gamma)U^{(-i)} \tag{34}$$

subject to the equations of the DE. The optimization process will result in the same system of 24 equations in 24 unknowns.

4.3 Gains from cooperation

We use a rather standard parameterization and our results are robust to changes in parameter values within commonly used parameter range. In particular we use: $A = 3.0$, $\alpha = 0.40$, $\beta = 0.90$, $\gamma = 0.5$, $\delta = 1.0$, $\mu_1 = 0.261$, $\mu_2 = 0.609$, $\mu_3 = 1 - \mu_1 - \mu_2$, $m = 0.01$, $k_1 = 0.1$, $g_1/y_1 = 0.2$, $b_1/y_1 = 0.3$. At this point we model countries that are identical to each other, with respect to TFP, time preference and discount rates, government spending as share of GDP, share of capital and initial conditions for capital stock and public debt. This will serve as a benchmark later on, when we will focus on asymmetries.

In *Table 1*, we present the Symmetric Non-Cooperative and Cooperative Equilibria. We find that our model validates the theoretical and empirical findings of Ramsey taxation, that under non-cooperative policies, tax rate on capital ($\tau_{k,2} = 7\%$) is below its efficient level and the public good is under provided. Interestingly, the weight of fiscal policy falls on labour taxation and in particular on first period tax rate, which amounts to $\tau_{l,1} = 73\%$. Obviously, the expansion of fiscal policy in the second period causes significant substitution effects and benefits all second-period fundamentals.

On the other hand, the cooperative equilibrium displays a smoother distribution of tax rates between the first and the second period. Capital tax rate is higher ($\tau_{k,2} = 50\%$), while labour tax rates are uniformly distributed between the two periods($\tau_{l,1} = 55\%, \tau_{l,2} = 52\%$). The smoothness of fiscal policy decreases the substitution effect and results in allocations which are distributed more balanced over time. Yet, under the burden of lower capital accumulation, the welfare gain from cooperation vis-á-vis Nash amounts to only 2.74%, proving that a high capital tax rate may be good for the provision of the public good, but it hurts private investment.

Table 1. Symmetric Nash and Cooperative equilibria, benchmark case

Ramsey Symmetric Nash Equilibrium					
Allocations		**Shares**		**Optimal Policy**	
c_1	0.1781	c_1/y_1	0.5560	τ_2^k	0.0706
c_2	0.3002	i_1/y_1	0.2440	τ_1^l	0.7285
k_2	0.0782	k_1/y_1	0.3121	τ_2^l	0.3249
b_2	-0.0031	g_1/y_1	0.2000	**Net Returns**	
l_1	0.1116	b_1/y_1	0.3000	R_1	0.0252
l_2	0.1855	c_2/y_2	0.7622	R_2	0.8728
s_2	1.0000	i_2/y_2	0.0000	W_1	0.4678
g_1	0.0641	k_2/y_2	0.1985	W_2	0.8600
g_2	0.0936	g_2/y_2	0.2378	**Gross Returns**	
y_1	0.3204	b_2/y_2	-0.0078	r_1	1.2815
y_2	0.3939			r_2	2.0152
Welfare				w_1	1.7229
W	-1.5517			w_2	1.2740

Ramsey Symmetric Coop Equilibrium					
Allocations		**Shares**		**Optimal Policy**	
c_1	0.2449	c_1/y_1	0.6320	τ_2^k	0.5072
c_2	0.2188	i_1/y_1	0.1680	τ_1^l	0.5554
k_2	0.0651	k_1/y_1	0.2581	τ_2^l	0.5264
b_2	0.0615	g_1/y_1	0.2000	**Net Returns**	
l_1	0.1532	b_1/y_1	0.3000	R_1	0.2399
l_2	0.1543	c_2/y_2	0.6675	R_2	-0.0074
s_2	1.0000	i_2/y_2	0.0000	W_1	0.6747
g_1	0.0775	k_2/y_2	0.1986	W_2	0.6036
g_2	0.1090	g_2/y_2	0.3325	**Gross Returns**	
y_1	0.3875	b_2/y_2	0.1876	r_1	1.5498
y_2	0.3277			r_2	2.0142
Welfare		**Coop V. Nash**		w_1	1.5178
W	-1.5092	(%) 2.74		w_2	1.2745

The message derived from *Table 1* is that cooperation is superior to non-cooperation in symmetric economies. In *Table 2*, we present optimal policy on the mobile factor (capital) and welfare gains from cooperation vis-á-vis Nash, at different values of initial debt-to-GDP ratio, s_1^b and TFP, A [4]. This simple robustness analysis supports, as expected, not only that cooperative policy is superior to Nash, but also that the cooperatively chosen tax rates are higher than Nash.

Table 2. Optimal policy on capital, τ_2^k, and welfare gains from cooperation vis-á-vis Nash, at different values of debt and TFP, in symmetric countries

Debt, Robustness				**TFP, robustness**			
	Optimal Policy		**Welfare** (%)		**Optimal Policy**		**Welfare** (%)
s_1^b	τ_2^k(Nash)	τ_2^k(Coop)	$\frac{W_{coop}-W_{nash}}{W_{nash}}$	A	τ_2^k(Nash)	τ_2^k(Coop)	$\frac{W_{coop}-W_{nash}}{W_{nash}}$
30%	0.07	0.51	**2.7**	6.0	0.09	0.62	**7.8**
40%	0.08	0.56	**3.7**	5.7	0.08	0.62	**7.3**
50%	0.08	0.60	**4.5**	5.4	0.08	0.61	**6.8**
60%	0.09	0.62	**5.1**	5.1	0.08	0.60	**6.3**
70%	0.09	0.64	**5.5**	4.8	0.08	0.59	**5.8**
80%	0.09	0.66	**5.9**	4.5	0.08	0.58	**5.2**
90%	0.09	0.67	**6.1**	4.2	0.08	0.57	**4.7**
100%	0.09	0.68	**6.3**	3.9	0.08	0.55	**4.2**
110%	0.09	0.69	**6.4**	3.6	0.08	0.54	**3.7**
120%	0.09	0.69	**6.5**	3.3	0.07	0.52	**3.2**
130%	0.09	0.70	**6.6**	3.0	0.07	0.51	**2.7**

Hence, in the benchmark case of symmetric economies, international cooperation is superior to non-cooperation (Nash), but, comes at the cost of lower private investment, due to the higher tax rates applied to the mobile factor. Note, that cooperation can be counter-productive when there are other distortions in the background, like politically motivated governments (*Persson and Tabellini, 1995*[22]), incomplete factor mobility (*Perotti, 2001*[21]), etc. In the next section we depart from symmetric countries and we focus on the role of cross-country asymmetries in public debt, institutional quality and TFP.

5 Optimal policies and allocations in asymmetric equilibria

We wonder what happens when countries differ. In other words, we revisit the comparison between non-cooperative (Nash) and cooperative fiscal policies in the presence of cross-country asymmetries. Specifically, we focus on cross-country asymmetries in public debt, institutional quality and TFP, which are considered to be among the striking differences between core and periphery EZ countries, especially after the 2008 crisis (*see e.g. Micossi, 2016*) and the data presented right below.

According to *Micossi (2016)*, general government debt in EU-Core(excl. Germany), EU-Periphery and Germany was converging to 60% of GDP, from 1995 to 2008. Since, the onset of the crisis, however, the EU-Periphery's aggregate public debt ratio almost doubled and EU-Core's ratio rose to 100% of GDP. On other hand, Germany recovered rapidly from the initial shock and witnessed its own public debt ratio decreasing to its pre-crisis level (*Figure 1*). Regarding, the quality of institutions we observe more of the same picture, as, after the start of the Euro, there was an evident deterioration of key institution indices in all EU countries, but even more strongly in the periphery. The drop in government effectiveness may be attributed to the crisis period, however, control of the rule of law and control of corruption, which also witnessed significant decline, cannot be directly related to the crisis (*Figure 2*).

[4] For a more detailed view on symmetric policies and allocations at different values of debt and TFP see *Tables 11 & 12* in Appendix.

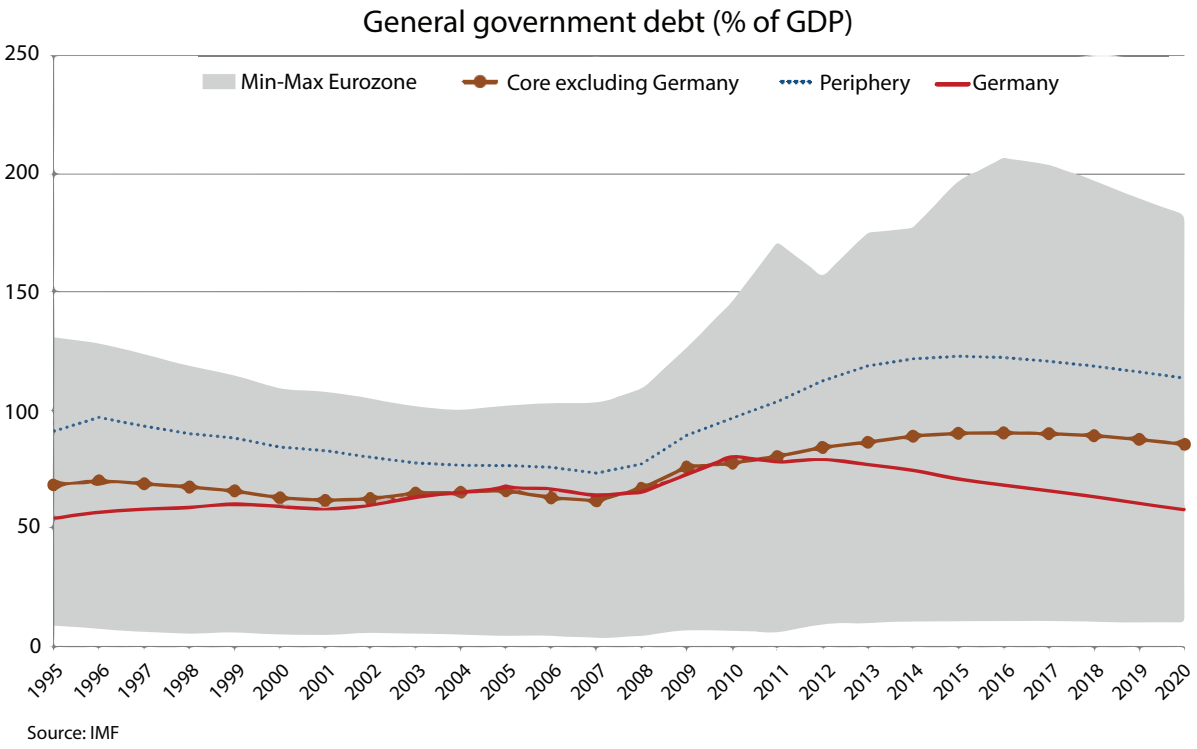

Figure 1: *Debt-to-GDP ratios for the EU-periphery, the EU-core(excluding Germany), and Germany, from 1995 to 2020(projections of 2016). Source: IMF*

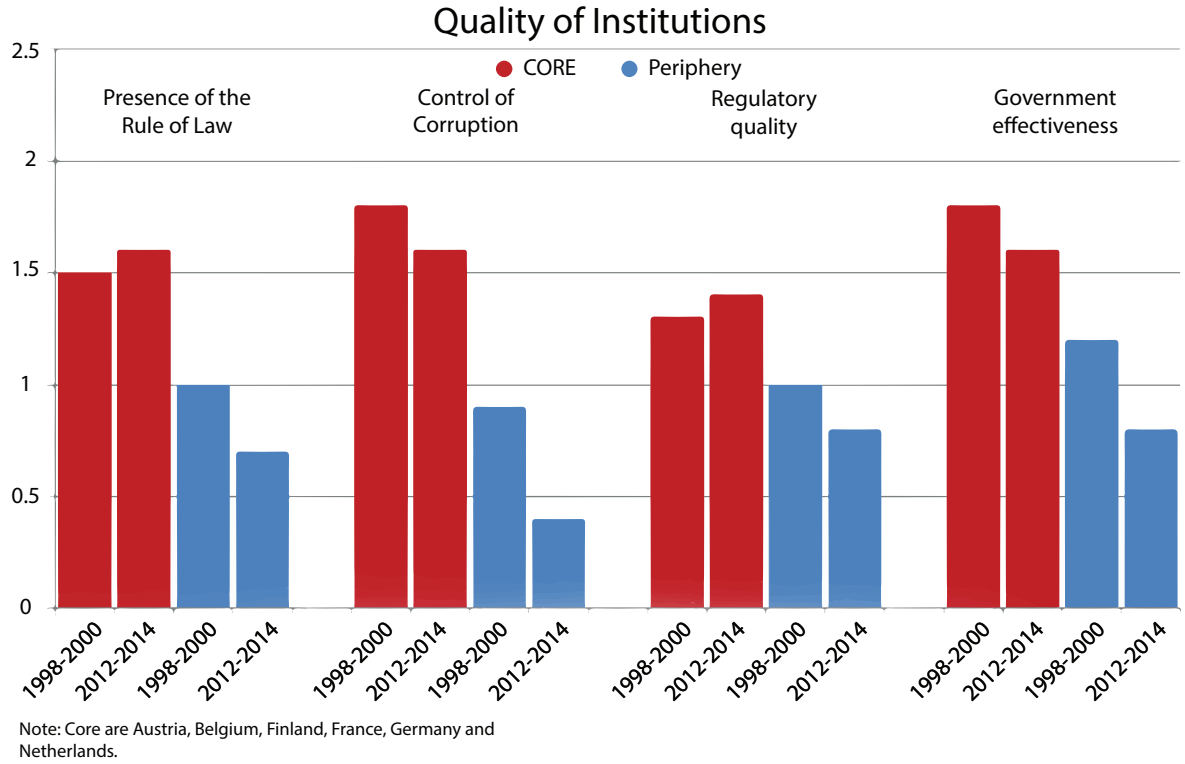

Figure 2: Institutional Quality in Euro-zone, Periphery, CORE and United States from 1995 to 2014, *Stefano Micossi,*

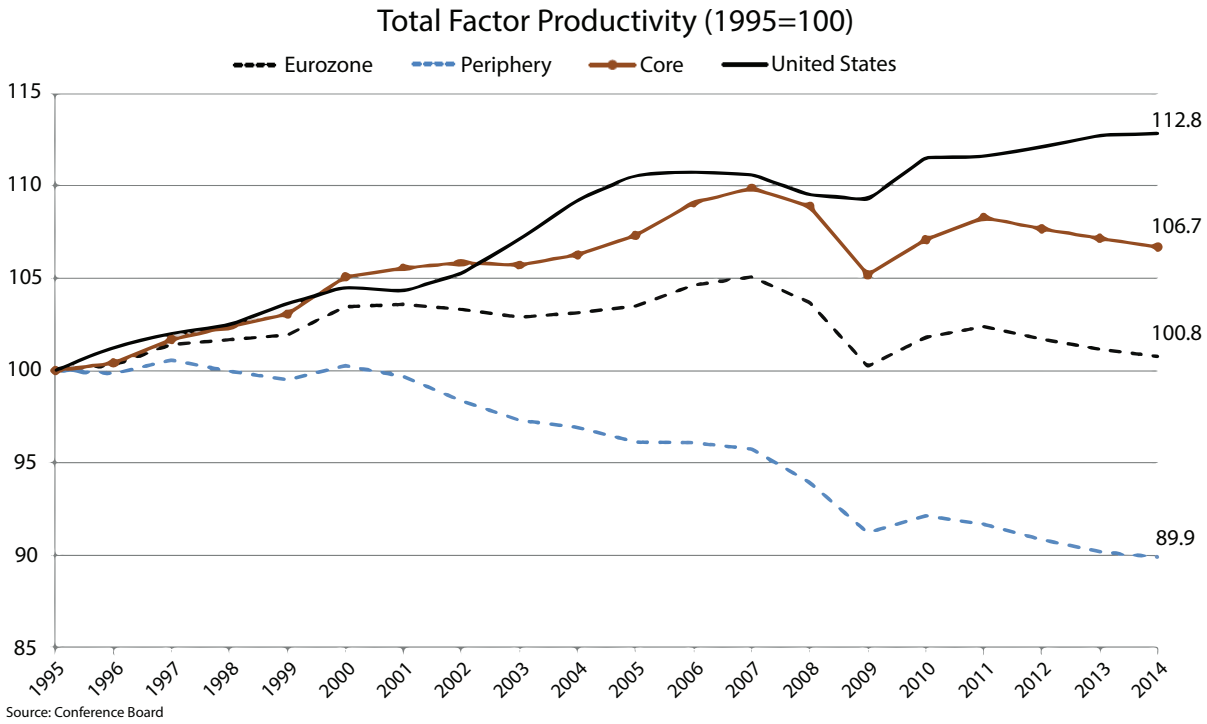

Figure 3: TFP in Euro-zone, Periphery, CORE and United States from 1995 to 2014, *Stefano Micossi, "Balance-of-payments adjustment in the Euro-zone", 2016*

These two figures could provide a partial explanation of the structural break in productivity that followed the years after the inception of the Euro and was more intense in the periphery economies (*figure 3*).

Motivated by the data, we enrich the model by allowing for public debt, institutional quality and TFP asymmetries. Specifically, we label one country as *"core"* and the other country as *"periphery"*. As it is the case in the data, the assumed asymmetries are:

1. Initial public debt-to-GDP is higher in the periphery
2. TFP is lower in the periphery
3. Institutional quality is lower in the periphery

Modelling asymmetries
In terms of modelling, asymmetries in public debt and TFP can be easily implemented. We do this by solving for optimal cooperative and non-cooperative equilibria at different values of initial debt-to-GDP, $s^b_{Per,1}$, and TFP, A_{Per}, of the periphery economy, while the respective parameters of the core economy are held intact. To model asymmetry in institutional quality, Θ_{Per}, we use a rather popular and generic way by assuming that firms in the periphery country can keep a fraction only of their output produced, because the rest is taken away by households that compete with each other for a share of this contestable prize.

Rigid Unions
Regarding the framework of cooperation we distinguish between flexible and rigid unions (*Alesina et al. 2005*). Cooperation under a flexible union implies that the cooperatively chosen tax rates are county-specific. On the other hand, in the case of a rigid union, there is a *"one-size-fits-all"* cooperatively chosen policy applied to all countries (like common tariff policy, tax harmonization, a single currency, etc.). To model this, we assume that the Ramsey planner maximises the same social welfare function, subject to the constraints of the DE, but instead of choosing a different tax rate for each economy, she now chooses

economy wide policy instruments for capital and labour, τ_2^k, τ_1^l and τ_2^l, respectively[5]. In the next subsection, we solve for three types of asymmetric equilibria:

i.non-cooperative(Nash),
ii.cooperative policies in a flexible union
iii.cooperative policies in a rigid union.

5.1 Public debt asymmetry

We solve the model for asymmetric cooperative and non-cooperative equilibria, at different values of initial debt-to-GDP ratio, $s^b_{Per,1}$, in the periphery country. In *Table 3*, we present the percentage welfare gains from flexible and rigid cooperation vis-á-vis Nash and the optimal policy on capital, for both economies. We observe that the higher the initial public debt-to-GDP ratio in the high-debt periphery country, the higher the gain from international cooperation for this country, but the lower the gain for the core country with healthy public finances. Actually, after a critical level of debt in the high-debt country (which is around 70% of GDP in our experiments), cooperation becomes counter-productive for the country with healthy public finances. Nevertheless, flexible cooperation is productive at aggregate or world level, mainly thanks to the gains enjoyed by the high-debt country.

Table 3. Welfare and optimal policy on capital under initial public debt asymmetry, $\uparrow s^b_{Per,1}$, $s^b_{Core,1} = 30\%$

Welfare % gains from cooperation							**Optimal policy on capital, τ_2^k**					
	Flex v. Nash %			**Rig v. Nash %**				**Core**		**Per**		
$s^b_{Per,1}$	W_{Core}	W_{Per}	W_{TOT}	W_{Core}	W_{Per}	W_{TOT}	$s^b_{Per,1}$	$Nash$	$Coop$	$Nash$	$Coop$	Rig
50%	1.4	5.6	3.6	1.3	3.3	2.3	50%	0.06	0.55	0.09	0.55	0.60
60%	0.8	6.6	3.8	-0.3	3.3	1.6	60%	0.05	0.56	0.10	0.57	0.63
70%	0.3	7.4	4.0	-2.2	3.3	0.7	70%	0.04	0.57	0.11	0.58	0.67
80%	-0.2	8.0	4.2	-4.1	3.2	-0.2	80%	0.04	0.58	0.11	0.59	0.69
90%	-0.6	8.5	4.3	-6.0	3.0	-1.2	90%	0.03	0.58	0.12	0.59	0.71
100%	-0.9	8.9	4.4	-7.9	2.8	-2.1	100%	0.03	0.59	0.12	0.60	0.73
110%	-1.2	9.2	4.4	-9.7	2.6	-3.1	110%	0.02	0.59	0.12	0.60	0.75
120%	-1.5	9.5	4.5	-11.4	2.3	-4.0	120%	0.02	0.59	0.12	0.61	0.76
130%	-1.7	9.7	4.5	-13.0	2.0	-4.8	130%	0.01	0.59	0.13	0.61	0.77

These results become more acute when cooperation is rigid. Specifically, in the case of rigid cooperation, the loss for the low-debt country is so big that now cooperation turns out to be counter-productive even at aggregate or world level at least in most cases studied. The mechanism behind these findings is the chosen tax policy. By choosing its tax policy jointly with a high-debt country that needs high tax revenues, the low-debt country, for the sake of cooperation, is forced to set relatively high tax rates as well, and this proves to be harmful for a country without its own fiscal imbalances. This problem gets worse with rigid cooperation. Summing up, cooperation (both flexible and rigid, but especially the latter) serves mainly the needs of high-debt countries.

In *Table 4* we take a closer look at the implications of debt asymmetry on tax rates, by providing the full range of optimal policies at the different values of periphery's debt. We report that in both countries, the cooperatively chosen tax rates on capital are higher than Nash and rise with the level of asymmetry, in all cases studied. Furthermore, as the periphery economy becomes more indebted, it relies more and more on labour taxation to finance its expenditures. This result is more acute when cooperation is rigid, as both capital and labour tax rates adjust accordingly to serve the needs of the high-debt country.

[5]See Appendix for a detailed view of modelling rigid unions.

Table 4. Optimal policies at different values of initial debt-to-GDP ratio, $s^b_{Per,1}$, of the periphery economy

	Core						**Periphery**						**Com Policy**		
	Nash			**Coop flex**			**Nash**			**Coop flex**			**Coop rig**		
$s^b_{Per,1}$	τ^k_2	τ^l_1	τ^l_2	τ^k_2	τ^l_1	τ^l_2	τ^k_2	τ^l_1	τ^l_2	τ^k_2	τ^l_1	τ^l_2	τ^k_2	τ^l_1	τ^l_2
50%	0.06	0.75	0.31	0.55	0.58	0.55	0.09	0.82	0.34	0.55	0.65	0.55	0.60	0.64	0.55
60%	0.05	0.76	0.30	0.56	0.60	0.56	0.10	0.84	0.34	0.57	0.68	0.56	0.63	0.68	0.56
70%	0.04	0.76	0.29	0.57	0.61	0.57	0.11	0.86	0.35	0.58	0.71	0.56	0.67	0.71	0.57
80%	0.04	0.77	0.28	0.58	0.62	0.57	0.11	0.88	0.35	0.59	0.74	0.56	0.69	0.74	0.58
90%	0.03	0.77	0.28	0.58	0.62	0.57	0.12	0.89	0.35	0.59	0.76	0.57	0.71	0.76	0.58
100%	0.03	0.78	0.27	0.59	0.63	0.57	0.12	0.90	0.36	0.60	0.77	0.57	0.73	0.78	0.59
110%	0.02	0.78	0.27	0.59	0.64	0.57	0.12	0.91	0.36	0.60	0.79	0.57	0.75	0.80	0.60
120%	0.02	0.78	0.26	0.59	0.64	0.58	0.12	0.91	0.36	0.61	0.80	0.57	0.76	0.81	0.60
130%	0.01	0.78	0.26	0.59	0.65	0.58	0.13	0.92	0.36	0.61	0.81	0.58	0.77	0.83	0.61

Table 5 is indicative of the capital flight effect and its impact on the allocations of each jurisdiction. The non-cooperative equilibrium barely affects consumption, c_2, capital, k_2, and labour, l_2 of the core economy, while it hurts dramatically the fundamentals of the periphery economy. As initial debt of the periphery rises, its private savings fall, foreign assets, f_2, become negative and the end-of-period public debt, b_2 rises.

Table 5. Allocations at different values of initial debt-to-GDP ratio, $s^b_{Per,1}$, of the periphery economy

Core															
	Nash					**Coop flex**					**Coop rig**				
$s^b_{Per,1}$	c_1	c_2	k_2	f_2	b_2	c_1	c_2	k_2	f_2	b_2	c_1	c_2	k_2	f_2	b_2
50%	0.17	0.30	0.08	0.01	-0.01	0.23	0.20	0.06	0.01	0.05	0.22	0.18	0.06	0.00	0.03
60%	0.16	0.30	0.07	0.01	-0.01	0.22	0.20	0.06	0.02	0.05	0.20	0.17	0.06	0.00	0.01
70%	0.16	0.30	0.07	0.02	-0.01	0.22	0.19	0.06	0.02	0.05	0.19	0.15	0.06	0.01	0.00
80%	0.16	0.31	0.07	0.02	-0.01	0.22	0.19	0.06	0.02	0.04	0.18	0.14	0.06	0.01	-0.01
90%	0.15	0.31	0.07	0.02	-0.01	0.21	0.19	0.06	0.03	0.04	0.17	0.13	0.06	0.01	-0.02
100%	0.15	0.31	0.07	0.02	-0.01	0.21	0.18	0.06	0.03	0.04	0.16	0.13	0.05	0.01	-0.02
110%	0.15	0.31	0.07	0.03	-0.02	0.21	0.18	0.06	0.03	0.04	0.15	0.12	0.05	0.01	-0.03
120%	0.15	0.31	0.07	0.03	-0.02	0.20	0.18	0.06	0.03	0.03	0.15	0.11	0.05	0.01	-0.03
130%	0.15	0.31	0.07	0.03	-0.02	0.20	0.18	0.06	0.03	0.03	0.14	0.11	0.05	0.01	-0.03
Periphery															
	Nash					**Coop flex**					**Coop rig**				
$s^b_{Per,1}$	c_1	c_2	k_2	f_2	b_2	c_1	c_2	k_2	f_2	b_2	c_1	c_2	k_2	f_2	b_2
50%	0.15	0.27	0.06	-0.01	0.01	0.23	0.20	0.05	-0.01	0.08	0.23	0.19	0.04	0.00	0.09
60%	0.14	0.26	0.05	-0.01	0.01	0.22	0.19	0.04	-0.02	0.09	0.22	0.18	0.03	0.00	0.10
70%	0.13	0.25	0.05	-0.02	0.01	0.21	0.18	0.03	-0.02	0.09	0.21	0.17	0.03	-0.01	0.10
80%	0.12	0.24	0.05	-0.02	0.01	0.20	0.18	0.03	-0.02	0.09	0.20	0.16	0.02	-0.01	0.10
90%	0.12	0.24	0.04	-0.02	0.02	0.20	0.17	0.03	-0.03	0.09	0.19	0.15	0.02	-0.01	0.10
100%	0.11	0.23	0.04	-0.02	0.02	0.19	0.17	0.02	-0.03	0.10	0.18	0.14	0.02	-0.01	0.10
110%	0.11	0.23	0.04	-0.03	0.02	0.19	0.17	0.02	-0.03	0.10	0.18	0.14	0.01	-0.01	0.10
120%	0.11	0.22	0.04	-0.03	0.02	0.18	0.16	0.02	-0.03	0.10	0.17	0.13	0.01	-0.01	0.10
130%	0.10	0.22	0.03	-0.03	0.02	0.18	0.16	0.02	-0.03	0.10	0.16	0.13	0.01	-0.01	0.10

However, when countries coordinate their actions, fundamentals present a more balanced picture. In a

flexible union, despite its proportional distribution between the two periods, consumption is decreasing to the level of debt asymmetry in both countries. Moreover, the cooperatively chosen tax rates hurt savings in the form of private capital, especially in the periphery economy. In the case of rigid cooperation the results are more acute.

5.2 Institutional quality asymmetry

We consider the case of property rights violation in the periphery economy. Specifically, we derive cooperative and non-cooperative equilibria at different values of rent extraction parameter Θ_{Per} in the periphery economy. Firstly, in terms of welfare, flexible cooperation is productive for both countries, although the gains from cooperation decrease with the degree of property rights violation. When cooperation is rigid, it becomes counter-productive in the country with poor institutional quality. Specifically, the core country enjoys higher gains from rigid cooperation, yet those gains are non-linear to the level of asymmetry and fade out after a critical point($\Theta_{Per} = 15\%$). On the other hand, the periphery economy suffers losses even at low degrees of violation*Table 6.*

Table 6. Welfare and optimal policy on capital under institutional quality asymmetry, $\uparrow \Theta_{Per}$, $\Theta_{Core} = 0.0$

Welfare % gains from cooperation						
	Flex v. Nash %			**Rig v. Nash %**		
Θ_{Per}	W_{Core}	W_{Per}	W_{TOT}	W_{Core}	W_{Per}	W_{TOT}
0%	2.7	2.7	2.7	2.7	2.7	2.7
2%	2.7	2.5	2.6	3.2	1.8	2.5
3%	2.6	2.4	2.5	3.3	1.4	2.3
4%	2.6	2.4	2.5	3.4	0.9	2.1
5%	2.6	2.3	2.4	3.4	0.5	1.9
6%	2.5	2.1	2.3	3.3	0.1	1.7
7%	2.5	2.0	2.3	3.1	-0.3	1.4
10%	2.4	1.7	2.1	2.3	-1.2	0.6
15%	2.3	1.2	1.7	0.3	-1.9	-0.8

Optimal policy on capital, τ_2^k					
	Core		**Per**		
Θ_{Per}	$Nash$	$Coop$	$Nash$	$Coop$	Rig
0%	0.07	0.51	0.07	0.51	0.51
2%	0.08	0.50	0.07	0.50	0.50
3%	0.08	0.50	0.07	0.49	0.50
4%	0.08	0.50	0.07	0.49	0.49
5%	0.08	0.50	0.07	0.48	0.49
6%	0.09	0.50	0.07	0.48	0.49
7%	0.09	0.50	0.07	0.47	0.48
10%	0.10	0.49	0.08	0.46	0.45
15%	0.11	0.48	0.08	0.43	0.37

Table 7. Optimal policies at different values of rent extraction, Θ_{Per}, of the periphery economy

	Core						**Periphery**						**Com Policy**		
	Nash			**Coop flex**			**Nash**			**Coop flex**			**Coop rig**		
Θ_{Per}	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l
0%	0.07	0.73	0.32	0.51	0.56	0.53	0.07	0.73	0.32	0.51	0.56	0.53	0.51	0.56	0.53
2%	0.08	0.72	0.33	0.50	0.56	0.52	0.07	0.73	0.32	0.50	0.57	0.52	0.50	0.57	0.51
3%	0.08	0.72	0.33	0.50	0.56	0.52	0.07	0.73	0.31	0.49	0.57	0.51	0.50	0.57	0.51
4%	0.08	0.72	0.33	0.50	0.55	0.52	0.07	0.73	0.31	0.49	0.58	0.50	0.49	0.58	0.50
5%	0.08	0.72	0.33	0.50	0.55	0.52	0.07	0.74	0.30	0.48	0.58	0.50	0.49	0.59	0.48
6%	0.09	0.72	0.33	0.50	0.55	0.52	0.07	0.74	0.30	0.48	0.59	0.49	0.49	0.60	0.47
7%	0.09	0.71	0.34	0.50	0.55	0.52	0.07	0.74	0.30	0.47	0.59	0.49	0.48	0.61	0.46
10%	0.10	0.71	0.34	0.49	0.55	0.52	0.08	0.74	0.28	0.46	0.61	0.47	0.45	0.65	0.42
15%	0.11	0.70	0.35	0.48	0.55	0.51	0.08	0.75	0.26	0.43	0.63	0.44	0.37	0.71	0.34

The mechanism behind these results is again the chosen tax policy. In general, recall that when property rights are weak, high tax rates on capital (an inherent property of cooperatively chosen tax rates on mobile

factors) would make resource misallocation and the low-investment problem even worse. Hence, relative to the previous case in which asymmetries took the form of high public debt, now the cooperatively chosen tax rates on capital are not that high and this is good for both countries. However, as institutional quality gets worse and worse, cooperatively set tax rates are a luxury and cooperation becomes counter-productive, especially for the country with worse institutions; the latter would prefer even lower tax rates.

The mutual gains from flexible cooperation in the presence of weak property rights can also be explained by the structure of labour tax rates. Indeed, the message derived from *Table 7* is that the cooperatively chosen tax rates follow a more balanced distribution not only between the two factors of production (capital and labour), but also within the two time periods. As a result, it comes as no surprise that the allocations in the two countries display a smooth picture.

Table 8. Labour supply at different values of rent extraction, Θ_{Per}, of the periphery economy

Core									
	Nash			**Coop flex**			**Coop rig**		
Θ_{Per}	l_1	l_2	s_2	l_1	l_2	s_2	l_1	l_2	s_2
0%	0.11	0.19	1.00	0.15	0.15	1.00	0.15	0.15	1.00
2%	0.11	0.19	1.00	0.15	0.16	1.00	0.15	0.17	1.00
3%	0.11	0.19	1.00	0.15	0.16	1.00	0.15	0.18	1.00
4%	0.11	0.19	1.00	0.15	0.16	1.00	0.14	0.18	1.00
5%	0.11	0.19	1.00	0.15	0.16	1.00	0.14	0.19	1.00
6%	0.11	0.19	1.00	0.15	0.16	1.00	0.13	0.20	1.00
7%	0.11	0.19	1.00	0.15	0.16	1.00	0.13	0.21	1.00
10%	0.11	0.19	1.00	0.15	0.16	1.00	0.12	0.23	1.00
15%	0.12	0.20	1.00	0.15	0.16	1.00	0.10	0.26	1.00
Periphery									
	Nash			**Coop flex**			**Coop rig**		
Θ_{Per}	l_1	l_2	s_2	l_1	l_2	s_2	l_1	l_2	s_2
0%	0.11	0.19	1.00	0.15	0.15	1.00	0.15	0.15	1.00
2%	0.11	0.19	0.95	0.15	0.16	0.93	0.15	0.15	0.93
3%	0.11	0.19	0.93	0.15	0.16	0.90	0.15	0.15	0.91
4%	0.11	0.19	0.91	0.15	0.17	0.88	0.15	0.15	0.88
5%	0.11	0.19	0.89	0.15	0.17	0.85	0.15	0.15	0.85
6%	0.11	0.19	0.87	0.14	0.17	0.83	0.15	0.15	0.83
7%	0.11	0.19	0.85	0.14	0.18	0.80	0.14	0.15	0.81
10%	0.11	0.20	0.79	0.14	0.18	0.74	0.14	0.15	0.76
15%	0.10	0.20	0.71	0.13	0.19	0.65	0.12	0.14	0.69

In *Table 8* we focus on the effect of weak property rights on labour supply, $l_{i,t}$, and productive labour supply, $s_{i,2}$, incentives. Since we have assumed that the core country fully protects the property rights of its residents, the amount of labour time that the households devote to productive work equals to one, meaning that they have no incentive to engage into rent extraction activities. However, in the economy with weak property rights, as the size of the contestable prize rises ($\Theta_{Per} \uparrow$), productive labor supply declines and households devote more and more of their productive time into rent extraction efforts. As in *Angelopoulos et al. (2011)*, we observe that with the rise of property rights violation comes an rise in second-period labour supply in both countries under non-cooperative and cooperative flexible policies. The intuition behind this result lies on two channels. The deterioration in property rights can be considered as a negative productivity shock which tends to decrease labour supply(as well as consumption, savings and output.[6] On the other hand, rent extraction becomes more productive inducing labour supply to rise. The latter effect dominates.

[6]For a more detailed view on allocations at different values of institutional quality in the periphery, see *Table 13* in Appendix.

5.3 TFP asymmetry

We also consider asymmetries in terms of TFP. As you can see in *Table 9*, flexible cooperation is productive for both economies, although the gains are decreasing to the level of asymmetry.

Table 9. Welfare and optimal policy on capital under TFP asymmetry, $\downarrow A_{Per}$, $A_{Core} = 6.0$

Welfare % gains from cooperation							**Optimal policy on capital, τ_2^k**					
	Flex v. Nash %			**Rig v. Nash %**				**Core**		**Per**		
A_{Per}	W_{Core}	W_{Per}	W_{TOT}	W_{Core}	W_{Per}	W_{TOT}	A_{Per}	$Nash$	$Coop$	$Nash$	$Coop$	Rig
5.4	7.2	7.4	7.3	9.3	4.8	7.0	5.4	0.10	0.63	0.07	0.60	0.62
5.1	6.8	7.1	6.9	9.7	3.2	6.3	5.1	0.11	0.63	0.06	0.59	0.61
4.8	6.3	6.7	6.6	9.8	1.6	5.4	4.8	0.12	0.64	0.05	0.58	0.60
4.5	5.9	6.4	6.1	9.6	0.1	4.4	4.5	0.13	0.64	0.04	0.56	0.59
4.2	5.3	5.9	5.7	9.0	-1.2	3.3	4.2	0.14	0.64	0.04	0.54	0.57
3.9	4.8	5.4	5.2	8.1	-2.4	2.2	3.9	0.15	0.64	0.03	0.53	0.54
3.6	4.2	4.9	4.6	6.8	-3.1	1.1	3.6	0.17	0.65	0.02	0.50	0.49
3.3	3.6	4.2	4.0	5.0	-3.2	0.2	3.3	0.18	0.65	0.01	0.48	0.41
3.0	2.9	3.5	3.3	2.8	-2.7	-0.5	3.0	0.20	0.65	0.00	0.45	0.32

However, when cooperation is rigid, it can become counter-productive not only in the country with low TFP, but also in the world economy. We observe that the non-cooperative capital tax rate is relatively low in both economies resulting in under-provision of the public good and reduction of the welfare.

Table 10. Optimal policies at different values of TFP, A_{Per}, of the periphery economy

	Core						**Periphery**						**Com Policy**		
	Nash			**Coop flex**			**Nash**			**Coop flex**			**Coop rig**		
A_{Per}	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l	τ_2^k	τ_1^l	τ_2^l
5.4	0.10	0.86	0.32	0.63	0.72	0.60	0.07	0.86	0.31	0.60	0.71	0.58	0.62	0.72	0.58
5.1	0.11	0.86	0.33	0.63	0.72	0.60	0.06	0.85	0.30	0.59	0.69	0.57	0.61	0.72	0.56
4.8	0.12	0.85	0.34	0.64	0.72	0.60	0.05	0.85	0.29	0.58	0.68	0.56	0.60	0.72	0.54
4.5	0.13	0.85	0.34	0.64	0.71	0.60	0.04	0.84	0.29	0.56	0.67	0.55	0.59	0.73	0.52
4.2	0.14	0.84	0.35	0.64	0.71	0.61	0.04	0.83	0.28	0.54	0.66	0.54	0.57	0.74	0.48
3.9	0.15	0.84	0.35	0.64	0.71	0.61	0.03	0.82	0.28	0.53	0.64	0.53	0.54	0.75	0.44
3.6	0.17	0.83	0.36	0.65	0.71	0.61	0.02	0.81	0.27	0.50	0.63	0.52	0.49	0.77	0.39
3.3	0.18	0.83	0.37	0.65	0.70	0.61	0.01	0.80	0.26	0.48	0.62	0.51	0.41	0.78	0.33
3.0	0.20	0.82	0.38	0.65	0.70	0.61	0.00	0.79	0.25	0.45	0.60	0.49	0.32	0.79	0.29

The mechanism behind these results becomes more clear in *Table 10*. In general, when TFP is low, high tax rates on capital (an inherent property of cooperatively chosen tax rates on mobile factors) would make the low investment problem of the low TFP economy even worse. In our case, cooperative tax rates are not that high and this is good for both countries. Notice, that flexible taxes are higher in the high TFP country and lower in the low TFP country. This explains the gains of the low TFP country in a union with flexible policy rules. Furthermore, the tax rate on the mobile factor is lower in a rigid union than in a flexible union and this promotes investment in the high TFP economy. Hence, flexible cooperation benefits both countries and especially the one with low TFP (it allows for lower tax rates in the low TFP country than in the high TFP country), while rigid cooperation is too restrictive for a country with low TFP that would prefer to

set higher tax rates on the mobile factor[7].

6 Conclusions and extensions

As the countries become more integrated, they engage more and more in tax competition for mobile factors, resulting in contraction of government revenues and under-provision of public goods. Theory suggests that this (Nash) equilibrium is self-defeating. Indeed, our study confirms that cooperation between symmetric economies is productive (i.e. it is preferable to non-cooperation). We showed that tax jurisdictions, when they act unilaterally, assign competitive capital tax rates, leading to under-provision of the public good and limited welfare level. Instead, if they cooperate, tax rates are typically higher and the public good is provided accordingly.

Nevertheless, as intuitive as it can be, the symmetric case barely describes the structural differences of the countries in an integrated world. It is a well-established fact that EU countries differ in several aspects such as public debt, institutional quality, TFP, etc. We depart from the baseline model and focus on cross-country asymmetries in public debt, institutional quality and TFP. We label one country as *"core"* and the other country as *"periphery"*. In particular, as it is the case in the data, we assume that

1. Initial public debt-to-GDP ratio is higher in periphery
2. TFP is lower in periphery
3. Institutional quality is worse in periphery

In terms of modelling, debt-to-GDP and TFP asymmetry can easily be implemented. We fix the respective parameters in the core country and then we solve for optimal policies at different parameter values of debt and TFP of the periphery economy. To model institutional quality, we use a popular and generic way by assuming that firms can keep a fraction only of their output produced, while the rest is expropriated by households who compete with other for a share of this contestable prize in a *Tullock-type* redistributive struggle. Furthermore, we assume that the cooperative framework can either be "flexible"or "rigid". Flexible cooperation implies that there can be country-specific chosen policies, while rigid cooperation implies a "one-size-fits-all"tax applied to both countries.

We find that in a union with flexible policy rules cooperation increases welfare vis-á-vis competition, yet, the lion's share of those gains is distributed disproportionally. If countries differ in initial debt-to-GDP ratio, cooperation (both flexible and rigid, but especially the latter) serves mainly the needs of high-debt countries. The low-debt country, for the sake of cooperation, is forced to set relatively high tax rates that serve the high-debt country, and this proves to be particularly harmful to its welfare. In the case of institutional quality asymmetries, flexible cooperation leads to relatively low tax rates on capital and this helps both economies. Tax rates are not that high because, in the presence of low factor returns due to poorly protected PRs, higher tax rates would make the problem of low factor accumulation even worse. On the other hand, rigid cooperation, can be too restrictive for a country with poor institutions, because it leads to excessively high tax rates. Our last experiment shows that if countries differ in TFP, flexible cooperation can benefit both countries and especially the one with low TFP (it allows for lower tax rates in the low TFP country than in the high TFP country), while, rigid cooperation is too restrictive for a country with low TFP. Rigid cooperation is too restrictive for a country with low TFP, as the cooperatively chosen tax rates make its low-investment problem even worse.

If we put all these results together, we prove that when several asymmetries are present, taking just one out is not necessarily productive (second-best result). Hence, the cooperative outcome is not always superior to

[7] *For a detailed view on allocations at different values of TFP in the periphery, see Table 14 in Appendix.*

the Nash, since it depends on the degree of asymmetry. Furthermore, we assumed that the social welfare function is the weighted average of the welfare of the household in each country with equal weights given to each country. We intend to assign different weights to the utility function of each country and perform the same experiments in the presence of asymmetries. Finally, we are planning to revisit optimal policies in the same model but from the point view of a time-consistent policy maker.

7 Appendix

Cooperation in a Rigid Union

The Ramsey planner maximises the weighted sum of welfare across the two countries, subject to the constraints of the DE. The only difference is that now there is a one-size-fits-all policy instrument for each factor applied to both countries.

$$W^{Rig} = \gamma U^{(i)} + (1-\gamma)U^{(-i)}$$

The Lagrange function is now

$$\begin{aligned}
L^{Rig} = W^{Rig} &+ \lambda_1\Big\{c_{i,1} + k_{i,2} - (1-\delta)k_{i,1} + f_{i,2} + g_{i,1} - y_{i,1}\Big\} \\
&\lambda_2\Big\{c_{i,2} - (1-\delta)k_{i,2} + g_{i,2} - y_{i,2} - (1-\tau_2^k)r_{i,2}f_{-i,2} - \{1 + (1-\tau_2^k) - \delta\}f_{i,2} + m\frac{f_{i,2}^2}{2}\Big\} \\
&\lambda_3\Big\{\frac{\mu_1}{c_{i,1}}(1-\tau_1^l)w_{i,1} - \frac{\mu_2}{1-l_{i,1}}\Big\} \\
&\lambda_4\Big\{\frac{c_{i,2}}{1-l_{i,2}} - \frac{\mu_1}{\mu_2}\{(1-\tau_2^l)(1-\Theta_i)(1-\alpha) + \Theta_i\}\frac{y_{i,2}}{l_{i,2}}\Big\} \\
&\lambda_5\Big\{s_{i,2} - \frac{(1-\tau_2^l)(1-\Theta_i)(1-\alpha)}{\Theta_i + (1-\tau_2^l)(1-\Theta_i)(1-\alpha)}\Big\} \\
&\lambda_6\Big\{c_{i,2} - \beta\Big\{1 + (1-\tau_2^k)r_{i,2} - \delta\Big\}c_{i,1}\Big\} \\
&\lambda_7\Big\{c_{i,2} - \beta\Big\{1 + (1-\tau_2^k)r_{-i,2} - \delta - mf_{i,2}\Big\}c_{i,1}\Big\} \\
&\lambda_8\Big\{g_{i,1} + (1 + (1-\tau_1^k)r_{i,1} - \delta)b_{i,1} - y_{i,1}(\alpha\tau_{i,1}^k + (1-\alpha)\tau_1^l) - b_{i,2}\Big\} \\
&\lambda_9\Big\{g_{i,2} + (1 + (1-\tau_2^k)r_{i,2} - \delta)b_{i,2} - (1-\Theta_i)y_{i,2}(\alpha\tau_2^k + (1-\alpha)\tau_2^l)\Big\} \qquad (35)
\end{aligned}$$

$$\begin{aligned}
&\lambda_{10}\Big\{c_{-i,1} + k_{-i,2} - (1-\delta)k_{-i,1} + f_{-i,2} + g_{-i,1} - y_{-i,1}\Big\} \\
&\lambda_{11}\Big\{c_{-i,2} - (1-\delta)k_{-i,2} + g_{-i,2} - y_{-i,2} - (1-\tau_{-i,2}^k)r_{-i,2}f_{i,2} - \{1 + (1-\tau_{i,2}^k) - \delta\}f_{-i,2} + m\frac{f_{-i,2}^2}{2}\Big\} \\
&\lambda_{12}\Big\{\frac{\mu_1}{c_{-i,1}}(1-\tau_{-i,1}^l)w_{-i,1} - \frac{\mu_2}{1-l_{-i,1}}\Big\} \\
&\lambda_{13}\Big\{\frac{c_{-i,2}}{1-l_{-i,2}} - \frac{\mu_1}{\mu_2}\{(1-\tau_{-i,2}^l)(1-\Theta_{-i})(1-\alpha) + \Theta_{-i}\}\frac{y_{-i,2}}{l_{-i,2}}\Big\} \\
&\lambda_{14}\Big\{s_{-i,2} - \frac{(1-\tau_{-i,2}^l)(1-\Theta_{-i})(1-\alpha)}{\Theta_{-i} + (1-\tau_{-i,2}^l)(1-\Theta_{-i})(1-\alpha)}\Big\} \\
&\lambda_{15}\Big\{c_{-i,2} - \beta\Big\{1 + (1-\tau_{-i,2}^k)r_{-i,2} - \delta\Big\}c_{-i,1}\Big\} \\
&\lambda_{16}\Big\{c_{-i,2} - \beta\Big\{1 + (1-\tau_{i,2}^k)r_{i,2} - \delta - mf_{-i,2}\Big\}c_{-i,1}\Big\} \\
&\lambda_{17}\Big\{g_{-i,1} + (1 + (1-\tau_{-i,1}^k)r_{-i,1} - \delta)b_{-i,1} - y_{-i,1}(\alpha\tau_{-i,1}^k + (1-\alpha)\tau_{-i,1}^l) - b_{-i,2}\Big\} \\
&\lambda_{18}\Big\{g_{-i,2} + (1 + (1-\tau_{-i,2}^k)r_{-i,2} - \delta)b_{-i,2} - (1-\Theta_{-i})y_{-i,2}(\alpha\tau_{-i,2}^k + (1-\alpha)\tau_{-i,2}^l)\Big\}
\end{aligned}$$

The optimization process yields a system of 21 equations in
1. Allocations $\{c_{i,1}, c_{i,2}, c_{-i,1}, c_{-i,2}, l_{i,1}, l_{i,2}, l_{-i,1}, l_{-i,2}, s_{i,2}, s_{-i,2}, k_{i,2}, k_{-i,2}, b_{i,2}, b_{-i,2}, f_{i,2}, f_{-i,2}\}$
2. Optimal policies $\{\tau_2^k, \tau_1^l, \tau_2^l, g_{i,2}, g_{-i,2}\}$.

Table 11. Symmetric cooperative and non-cooperative policies and gains or losses from cooperation vis-á-vis Nash, at different values of debt-to-GDP ratio, s_1^b

Debt Robustness - Symmetric Equilibria														
	Nash				**Cooperation**				**Gains or losses from cooperation %**					
	Policy								**Welfare and Allocations**					
A	τ_2^k	τ_1^l	τ_2^l	g_2	τ_2^k	τ_1^l	τ_2^l	g_2	Wel	k_2	c_1	c_2	y_1	y_2
30%	0.07	0.73	0.32	0.09	0.51	0.56	0.53	0.11	**2.7**	**-16.8**	**37.5**	**-27.1**	**20.9**	**-16.8**
40%	0.08	0.79	0.32	0.08	0.56	0.62	0.56	0.10	**3.7**	**-18.7**	**46.9**	**-30.8**	**27.2**	**-19.8**
50%	0.08	0.84	0.32	0.08	0.60	0.68	0.58	0.09	**4.5**	**-20.2**	**54.9**	**-33.6**	**32.7**	**-22.2**
60%	0.09	0.87	0.31	0.07	0.62	0.73	0.59	0.08	**5.1**	**-21.4**	**61.8**	**-35.7**	**37.3**	**-24.1**
70%	0.09	0.89	0.31	0.06	0.64	0.76	0.60	0.08	**5.5**	**-22.5**	**67.5**	**-37.3**	**41.1**	**-25.6**
80%	0.09	0.91	0.31	0.06	0.66	0.80	0.61	0.07	**5.9**	**-23.4**	**72.2**	**-38.6**	**44.4**	**-26.8**
90%	0.09	0.92	0.31	0.06	0.67	0.82	0.62	0.07	**6.1**	**-24.1**	**76.1**	**-39.5**	**47.0**	**-27.8**
100%	0.09	0.93	0.31	0.06	0.68	0.84	0.63	0.07	**6.3**	**-24.6**	**79.5**	**-40.3**	**49.2**	**-28.6**
110%	0.09	0.94	0.30	0.05	0.69	0.86	0.63	0.06	**6.4**	**-24.8**	**82.2**	**-41.0**	**51.0**	**-29.2**
120%	0.09	0.95	0.30	0.05	0.69	0.88	0.63	0.06	**6.5**	**-25.7**	**84.3**	**-41.5**	**52.6**	**-29.7**
130%	0.09	0.96	0.30	0.05	0.70	0.89	0.64	0.06	**6.6**	**-25.8**	**86.4**	**-42.0**	**53.9**	**-30.2**

Table 12. Symmetric cooperative and non-cooperative policies and gains or losses from cooperation vis-á-vis Nash, at different values of TFP, A

TFP Robustness - Symmetric Equilibria														
	Nash				**Cooperation**				**Gains or losses from cooperation %**					
	Policy								**Welfare and Allocations**					
A	τ_2^k	τ_1^l	τ_2^l	g_2	τ_2^k	τ_1^l	τ_2^l	g_2	Wel	k_2	c_1	c_2	y_1	y_2
6.0	0.09	0.87	0.31	0.18	0.62	0.73	0.59	0.22	**7.8**	**-21.5**	**61.8**	**-35.7**	**37.3**	**-24.1**
5.7	0.08	0.86	0.31	0.17	0.62	0.71	0.59	0.21	**7.3**	**-21.1**	**59.9**	**-35.1**	**36.0**	**-23.6**
5.4	0.08	0.85	0.32	0.17	0.61	0.70	0.58	0.20	**6.8**	**-20.7**	**57.9**	**-34.5**	**34.6**	**-23.0**
5.1	0.08	0.84	0.32	0.16	0.60	0.69	0.58	0.19	**6.3**	**-20.4**	**55.7**	**-33.8**	**33.1**	**-22.4**
4.8	0.08	0.83	0.32	0.15	0.59	0.67	0.57	0.18	**5.8**	**-19.9**	**53.4**	**-33.1**	**31.6**	**-21.7**
4.5	0.08	0.82	0.32	0.14	0.58	0.65	0.57	0.16	**5.2**	**-19.5**	**51.1**	**-32.3**	**30.0**	**-21.0**
4.2	0.08	0.80	0.32	0.13	0.57	0.64	0.56	0.15	**4.7**	**-19.0**	**48.6**	**-31.4**	**28.3**	**-20.3**
3.9	0.08	0.79	0.32	0.12	0.55	0.62	0.55	0.14	**4.2**	**-18.5**	**46.0**	**-30.5**	**26.6**	**-19.5**
3.6	0.08	0.77	0.32	0.11	0.54	0.60	0.54	0.13	**3.7**	**-18.0**	**43.2**	**-29.5**	**24.8**	**-18.7**
3.3	0.07	0.75	0.32	0.10	0.52	0.58	0.54	0.12	**3.2**	**-17.4**	**40.4**	**-28.3**	**22.9**	**-17.7**
3.0	0.07	0.73	0.32	0.09	0.51	0.56	0.53	0.11	**2.7**	**-16.8**	**37.5**	**-27.1**	**20.9**	**-16.8**

Table 13. Allocations at different values of property rights protection, Θ_{Per}, of the periphery economy

	Nash								Coop flex								Coop rig							
Core																								
Θ_{Per}	c_1	c_2	k_2	f_2	b_2	l_1	l_2	s_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2	s_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2	s_2
0%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.24	0.22	0.07	0.00	0.06	0.15	0.15	1.00	0.24	0.22	0.07	0.00	0.06	0.15	0.15	1.00
2%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.25	0.22	0.07	0.00	0.06	0.15	0.16	1.00	0.24	0.22	0.07	-0.01	0.06	0.15	0.17	1.00
3%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.25	0.22	0.07	0.00	0.06	0.15	0.16	1.00	0.24	0.22	0.07	-0.01	0.05	0.15	0.18	1.00
4%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.25	0.22	0.07	0.00	0.06	0.15	0.16	1.00	0.24	0.22	0.07	-0.01	0.05	0.14	0.18	1.00
5%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.25	0.22	0.07	0.00	0.06	0.15	0.16	1.00	0.24	0.22	0.07	-0.01	0.04	0.14	0.19	1.00
6%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.25	0.22	0.07	0.00	0.06	0.15	0.16	1.00	0.24	0.23	0.07	-0.01	0.04	0.13	0.20	1.00
7%	0.19	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.25	0.22	0.07	0.00	0.06	0.15	0.16	1.00	0.23	0.23	0.07	-0.02	0.03	0.13	0.21	1.00
10%	0.19	0.30	0.08	-0.01	0.00	0.11	0.19	1.00	0.25	0.22	0.07	0.00	0.06	0.15	0.16	1.00	0.22	0.23	0.07	-0.02	0.02	0.12	0.23	1.00
15%	0.19	0.30	0.08	-0.01	0.01	0.12	0.20	1.00	0.25	0.23	0.07	-0.01	0.06	0.15	0.16	1.00	0.20	0.25	0.07	-0.03	-0.01	0.10	0.26	1.00
Periphery																								
	Nash								**Coop flex**								**Coop rig**							
Θ_{Per}	c_1	c_2	k_2	f_2	b_2	l_1	l_2	s_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2	s_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2	s_2
0%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	1.00	0.24	0.22	0.07	0.00	0.06	0.15	0.15	1.00	0.24	0.22	0.07	0.00	0.06	0.15	0.15	1.00
2%	0.18	0.30	0.08	0.00	0.00	0.11	0.19	0.95	0.24	0.22	0.06	0.00	0.06	0.15	0.16	0.93	0.24	0.22	0.06	0.01	0.06	0.15	0.15	0.93
3%	0.18	0.29	0.07	0.00	0.00	0.11	0.19	0.93	0.24	0.22	0.06	0.00	0.05	0.15	0.16	0.90	0.24	0.22	0.06	0.01	0.06	0.15	0.15	0.91
4%	0.18	0.29	0.07	0.00	-0.01	0.11	0.19	0.91	0.24	0.22	0.06	0.00	0.05	0.15	0.17	0.88	0.23	0.22	0.06	0.01	0.05	0.15	0.15	0.88
5%	0.18	0.29	0.07	0.00	-0.01	0.11	0.19	0.89	0.24	0.21	0.06	0.00	0.05	0.15	0.17	0.85	0.23	0.22	0.06	0.01	0.05	0.15	0.15	0.85
6%	0.18	0.28	0.07	0.00	-0.01	0.11	0.19	0.87	0.24	0.21	0.06	0.00	0.05	0.14	0.17	0.83	0.23	0.22	0.06	0.01	0.04	0.15	0.15	0.83
7%	0.17	0.28	0.07	0.00	-0.01	0.11	0.19	0.85	0.23	0.21	0.06	0.00	0.04	0.14	0.18	0.80	0.22	0.22	0.06	0.02	0.04	0.14	0.15	0.81
10%	0.17	0.27	0.07	0.01	-0.01	0.11	0.20	0.79	0.23	0.21	0.06	0.00	0.04	0.14	0.18	0.74	0.21	0.22	0.06	0.02	0.03	0.14	0.15	0.76
15%	0.17	0.26	0.06	0.01	-0.01	0.10	0.20	0.71	0.22	0.20	0.06	0.01	0.03	0.13	0.19	0.65	0.18	0.22	0.06	0.03	0.01	0.12	0.14	0.69

Table 14. Allocations at different values of TFP, A_{Per}, of the periphery economy

	Nash							Coop flex							Coop rig						
Core																					
A_{Per}	c_1	c_2	k_2	f_2	b_2	l_1	l_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2
5.4	0.25	0.68	0.10	-0.01	0.01	0.06	0.19	0.39	0.43	0.08	0.00	0.15	0.10	0.14	0.40	0.45	0.08	-0.01	0.14	0.09	0.15
5.1	0.26	0.68	0.10	-0.01	0.01	0.06	0.19	0.40	0.43	0.08	0.00	0.15	0.10	0.14	0.40	0.46	0.08	-0.02	0.14	0.09	0.16
4.8	0.26	0.68	0.10	-0.01	0.01	0.06	0.19	0.40	0.43	0.08	0.00	0.15	0.10	0.14	0.40	0.47	0.08	-0.03	0.13	0.09	0.18
4.5	0.27	0.67	0.10	-0.01	0.02	0.06	0.19	0.40	0.43	0.08	0.00	0.15	0.10	0.14	0.40	0.49	0.08	-0.03	0.12	0.09	0.19
4.2	0.27	0.67	0.10	-0.02	0.02	0.06	0.19	0.40	0.43	0.08	0.00	0.16	0.10	0.14	0.39	0.51	0.08	-0.04	0.10	0.08	0.20
3.9	0.28	0.67	0.10	-0.02	0.03	0.06	0.20	0.41	0.42	0.08	0.00	0.16	0.10	0.14	0.38	0.54	0.08	-0.04	0.09	0.08	0.22
3.6	0.29	0.67	0.11	-0.02	0.03	0.06	0.20	0.41	0.42	0.08	-0.01	0.16	0.10	0.14	0.37	0.58	0.08	-0.05	0.07	0.07	0.23
3.3	0.30	0.67	0.11	-0.03	0.04	0.07	0.20	0.41	0.42	0.08	-0.01	0.16	0.10	0.14	0.36	0.63	0.08	-0.05	0.06	0.07	0.24
3.0	0.31	0.66	0.11	-0.03	0.04	0.07	0.20	0.41	0.42	0.08	-0.01	0.17	0.10	0.14	0.34	0.68	0.09	-0.06	0.05	0.07	0.24
Periphery																					
	Nash							**Coop flex**							**Coop rig**						
A_{Per}	c_1	c_2	k_2	f_2	b_2	l_1	l_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2	c_1	c_2	k_2	f_2	b_2	l_1	l_2
5.4	0.22	0.61	0.10	0.01	0.00	0.06	0.18	0.36	0.40	0.08	0.00	0.12	0.10	0.14	0.35	0.39	0.08	0.01	0.12	0.10	0.13
5.1	0.21	0.57	0.09	0.01	0.00	0.07	0.17	0.35	0.38	0.08	0.00	0.11	0.11	0.14	0.32	0.37	0.08	0.02	0.10	0.10	0.12
4.8	0.21	0.53	0.09	0.01	-0.01	0.07	0.17	0.33	0.36	0.08	0.00	0.11	0.11	0.14	0.30	0.35	0.08	0.03	0.08	0.11	0.12
4.5	0.20	0.49	0.09	0.01	-0.01	0.07	0.17	0.32	0.34	0.08	0.00	0.10	0.12	0.14	0.27	0.33	0.07	0.03	0.06	0.11	0.12
4.2	0.19	0.46	0.09	0.02	-0.01	0.08	0.16	0.30	0.32	0.07	0.00	0.09	0.12	0.14	0.24	0.31	0.07	0.04	0.04	0.11	0.11
3.9	0.18	0.42	0.08	0.02	-0.01	0.08	0.16	0.28	0.30	0.07	0.00	0.07	0.13	0.15	0.21	0.30	0.07	0.04	0.02	0.11	0.11
3.6	0.17	0.39	0.08	0.02	-0.01	0.09	0.15	0.26	0.27	0.07	0.01	0.06	0.13	0.15	0.19	0.29	0.07	0.05	0.01	0.11	0.10
3.3	0.16	0.35	0.08	0.03	-0.02	0.10	0.14	0.25	0.25	0.07	0.01	0.05	0.14	0.15	0.16	0.28	0.07	0.05	-0.01	0.11	0.08
3.0	0.14	0.31	0.07	0.03	-0.02	0.10	0.13	0.23	0.23	0.07	0.01	0.04	0.14	0.15	0.13	0.27	0.07	0.06	-0.02	0.11	0.06

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