Nationally and Internationally Optimal Climate Policies: External Balances versus Environmental Preferences

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Abstract

This paper compares nationally optimal to internationally optimal (Pareto efficient) emission permit levels in a two–country overlapping generations model with national emission permit systems and the environment as a global public good. When each government maximises its steady state economic and environmental welfare and one country is a net foreign creditor and the other one a net foreign debtor, it is nationally optimal for the creditor country with sufficiently high environmental preferences to chose a stricter permit level than the debtor country. However, the resulting Nash equilibrium permit levels are not Pareto efficient. Depending on the direction and strength of the countries' differences in external balances and environmental preferences, Pareto efficiency mandates that their permit levels are either adjusted in opposite directions or reduced both.

Keywords: emission permit policies, external balance, environmental preferences, Nash equilibrium, Pareto efficiency.

JEL Codes: F59; Q54; D62.

1 Introduction

After COP–15 in Copenhagen, national interests dominate negotiations for Post–Kyoto climate policy. While the failure of a multilateral approach to Post–Kyoto is deplored in both media and science, trade theory and the theory of fiscal competition suggest that nationally optimal emission reduction policies can also be internationally optimal thus denying the necessity of international cooperation. In this paper, we challenge this suggestion and point out how and why nationally and internationally optimal emission reduction policies diverge even among similarly developed countries like the EU and the US.

A possible explanation for the EU–US divide in regard to climate change policy is that in the US perceived domestic costs of climate policy are higher while benefits of doing so are lower (see, e.g. Tol, 2001; Pearce, 2003; Buchner and Carraro, 2004; Eyckmans and Finus, 2007; Osmani and Tol, 2009). We argue that differences in perceived costs of climate policy in terms of domestic welfare are influenced by external balances, while differences in perceived benefits of climate change policy are based on diverging public environmental preferences. Comparing the EU to the US, there is evidently a difference both in external balances (IMF, 2006, 2008) and in environmental preferences of citizens (Böhringer and Vogt, 2004) which might help to explain differences in their policy approaches.

Starting with external balances, differences in welfare consequences of unilateral and multilateral climate policies across industrialised countries are caused by diverging net foreign asset positions. In an intertemporal two–country model with trade in commodities and government bonds, the economic welfare losses of an exogenous reduction in emission permits are higher for a net foreign debtor country than for a net foreign creditor country (Bednar-Friedl *et al.*, 2010). When moreover the resulting environmental welfare gains are not too large, a net foreign debtor country is better off by awaiting the consequences of unilateral policy abroad than by agreeing to a multilateral policy (with similar environmental effects as the unilateral policy) (Bednar-Friedl and Farmer, 2010).

This paper seeks to complement this research by providing a rigourous theoretical analysis on how such differences in environmental preferences, relative to differences in external balances, influence strategic policy decisions.

While the extensive game–theoretic literature (for a survey, see e.g. Finus, 2008) has shaped our understanding of why so little has been achieved in mitigating climate change, there is increasing recognition that linkages through international trade change these results. When international trade in goods is introduced, the basic game theoretic result, which finds that cooperative policies (internationally optimal) are in general more stringent than non–cooperative policies (nationally optimal) (Hoel, 1991; Barrett, 1994; Carraro and Siniscalco, 1998), does not hold any longer. Due to terms of trade effects, a uniform exogenous reduction in permit levels in two industrialised countries can now be internationally efficient (Copeland and Taylor, 2005).

This trade–theoretic efficiency result is also strengthened by models of fiscal competition with mobile capital and local public goods (Oates and Schwab, 1988). In such a model, Ogawa and Wildasin (2009) find that interjurisdictional spillovers affecting the environment are efficiently internalised by decentralised (nationally optimal) policies. These findings result however from static general equilibrium models with exogenously fixed global capital, which might not hold in intertemporal general equilibrium models with endogenous capital formation.

Drawing on these different strands of literature, the present paper sets out to answer three fundamental questions: (i) Under the assumption that each national government determines endogenously its emission permit levels by maximising the sum of economic and environmental welfare, how are differences in nationally optimal permit levels driven by the external balances and/or environmental preferences of the respective countries? (ii) Are these nationally optimal emission permit levels internationally optimal (Pareto efficient), in line with the trade–based and fiscal competition arguments of the efficiency of nationally optimal policy setting? (iii) And if not, are they lower than the nationally optimal solution, in line with the autarky equilibrium game–theoretic literature?

The methodological novelty of the present paper is that we combine two economic approaches: an intertemporal general equilibrium model of the overlapping generations (OLG) type that captures the feedback effect between production, international trade (in goods and government bonds), capital accumulation and the environment, and an optimal policy analysis that determines nationally and internationally optimal climate policy strategies (emission permit levels) for two industrialised countries.[1]

To derive the economic and environmental welfare consequences of different climate change policies we employ a dynamic general equilibrium model with trade in commodities and government bonds. This two–country two–good OLG model is essentially the same as in Bednar-Friedl and Farmer (2010), where greenhouse gas emissions are caused by production, affect negatively global environmental quality, and are controlled by national emission permit systems. One important extension of the former model is that the two countries are assumed to differ not only in their external balances but also in their environmental preferences, and that emission permit levels are now determined endogenously in an optimal policy approach.

To single out the influence of the external balance and the environmental preferences of the involved countries for their strategic permit policy choices, we follow the approach of optimal trade policy (Bagwell and Staiger, 1999) by deriving the national welfare maximising permit levels for each of the two countries given the choices of the other country. This also involves a characterisation of how environmental preferences and/or external balances influence the relative stringency of nationally optimal permit levels across countries. The second step comprises investigating whether these nationally optimal permit levels are also internationally optimal, and if they are not, how nationally optimal permit levels need to be adjusted to ensure Pareto efficiency. We find that nationally optimal permit levels are not only internationally non-optimal, but that depending on the country differences in the external balance and in the environmental preferences one country needs to reduce and the other country needs to increase its permit level to achieve Pareto efficiency. Only when countries differ a lot, such that the net foreign creditor country has considerably lower environmental preferences and moreover the net foreign debtor country is characterised by a large external deficit, both countries need to reduce their permit levels.

[1] A related approach of synthesising strategic and economic aspects of climate policy has been followed previously by combining a game–theoretic analysis (i.e. coalition theory) with either a multi-country integrated assessment model (Eyckmans and Finus, 2007; Bréchet *et al.*, 2010) or a static multi-country multi-sector computable general equilibrium trade model (Carbone *et al.*, 2009).

This paper has five sections. In the next section we provide a description of the two–country, two–good model with nationally tradable emission permits and derive the intertemporal equilibrium dynamics and the steady state solutions. We investigate the nationally optimal permit levels in Section 3, while Section 4 is devoted to a thorough analysis of different internationally optimal solutions conditional on external balances and environmental preferences of the two countries. Section 5 summarises our results and concludes.

2 The basic model

As stated above, the methodological novelty of our approach is to combine a dynamic general equilibrium model with an optimal policy framework. This section summarises the main features of the two–country two–good OLG model which will be used for the derivation of nationally and internationally optimal permit policies in the subsequent sections. For a more extensive analysis of the model properties, particularly in regard to existence and stability, we refer to Bednar-Friedl and Farmer (2010).[2] Consider an infinite–horizon world economy of two countries, Home H and Foreign F, which have the same population normalised to unity. Each country is composed of perfectly competitive firms and finitely lived consumers. To keep the model as simple as possible, both countries are perfectly symmetric in terms of endowments and technology, but differ in environmental preferences. Countries differ also in their levels of public debt per capita, leading to diverging external balances (net foreign asset positions) across countries. For the real world application we have in mind, we assume that the domestic country is a net foreign creditor (the EU-15) while the foreign country is a net foreign debtor to the world economy (the US).

There are two tradeable goods, x and y^*, and each country specialises in the production of a unique good, which can be used for the purpose of consumption in both countries as well as for investment. Both goods are produced by employing labour and capital, and both

[2] The present model differs however in two respects from the model analysed there: countries differ in their environmental preferences, but production technologies are similar.

cause a flow of pollution. Households save in terms of internationally immobile capital and internationally mobile government bonds, where the supply of government bonds in each country is constant over time (as in Diamond, 1965). Without loss of generality, the rate of depreciation can be set at one, enabling investment of the current period to form next period's capital stock.

Regarding greenhouse gas emissions and climate policy, we follow the established approach in closed economy OLG models (Ono, 2002; Jouvet *et al.*, 2005; Bréchet *et al.*, 2009) and focus on emissions from production that are regulated by an emissions permit trading system. We assume that each country implements a domestic emissions trading system with a politically set cap on carbon emissions. The initial allocation of permits to the firms is grandfathering.

2.1 Firms

Let the domestically produced good be x and the foreign–produced good be y^*, both in per capita terms (in the following, all foreign–country variables are denoted by a superscript asterisk). Both countries have similar Cobb–Douglas constant–returns–to–scale production technology:

$$x_t = M\left(k_t\right)^{\alpha_K}\left(p_t\right)^{\alpha_P}, \qquad\qquad y_t^* = M(k_t^*)^{\alpha_K}(p_t^*)^{\alpha_P},$$

where M denotes a productivity scalar, k_t (k_t^*) and p_t (p_t^*) are respectively the capital–labour ratio and the pollution–labour ratio in H (F).

In each country, the long-lived government sets an emission permit level, denoted by S in Home and by S^* in Foreign.[3] In each period, firms in Home (and analogously for Foreign) choose k and p to maximise profits $\pi_t = x_t - q_t k_t - w_t + e_t\left(S - p_t\right)$, where q_t (q_t^*) is the rental price of capital, w_t (w_t^*) is the wage rate, and e_t (e_t^*) is the permit price in Home

[3]Since in all industrialised countries pollution is regulated, at least partially, by environmental law, we assume without loss of generality that both countries limit their emissions at levels S and S^*. Applied to the example of the EU, S corresponds to the cap on the European Emissions Trading Scheme, while for the US S^* represents e.g. emission standards such as CAFE to curb pollution. Following Ono (2002), emission permits are distributed free of charge to the firms.

(Foreign). Since excess emission permits are traded in a perfectly competitive market and, moreover, firms rent capital and employ labour in perfect factor markets, the optimality conditions for maximising profits in each period are given by:

$$q_t = \alpha_K \frac{x_t}{k_t}, \qquad w_t = (1 - \alpha_K - \alpha_P)\, x_t, \qquad e_t = \alpha_P \frac{x_t}{p_t}, \tag{1}$$

$$q_t^* = \alpha_K \frac{y_t^*}{k_t^*}, \qquad w_t^* = (1 - \alpha_K - \alpha_P)\, y_t^*, \qquad e_t^* = \alpha_P \frac{y_t^*}{p_t^*}. \tag{1*}$$

Profit maximisation implies that the firm's revenues net of the payments to production factors give a profit equal to the initial endowment of permits, $e_t S$. This profit is collected by the government and used, together with the a lump-sum tax on younger households, to pay the interest on public debt (see (9) below).[4]

2.2 Households and governments

Each country is inhabited by identical consumers which live for two periods, one working and one retirement period. The representative consumer's intertemporal utility depends on consumption during the working period, composed of the consumption goods of both countries, x_t^1 and y_t^1, consumption during the retirement period, x_{t+1}^2 and y_{t+1}^2, as well as on future global environmental quality E_{t+1}. E_{t+1} can be interpreted as the state of the atmosphere which is affected by anthropogenic greenhouse gas emissions. It is reasonable to assume that households care for E_{t+1} because reducing emissions today will affect the climate approximately fifty years later (IPCC, 2007). For simplicity, the representative households of countries H and F are assumed to have identical preferences across goods ($0 < \zeta < 1$), and over time ($0 < \beta < 1$), but different ones with regard to global environmental quality ($\xi > 0$, $\xi^* > 0$).

Since one of the main characteristics of our model are diverging environmental preferences, let us briefly discuss the implications of our modeling. As in Carbone *et al.* (2009), marginal utility of reductions in global emissions are constant but different across countries. $\xi^* < \xi$ would correspond to common parameterisations in the game–theoretic literature

[4]In essence, this particular modeling of the permit system guarantees that the subsidy is non–distortionary.

(Tol, 2001; Pearce, 2003; Buchner and Carraro, 2004; Eyckmans and Finus, 2007; Osmani and Tol, 2009), reflecting that perceived benefits of mitigating climate change are lower in the US than Europe. However, rather than assuming $\xi^* < \xi^*$, we consider both cases that either environmental preferences are stronger or weaker in Foreign compared to Home.

As in e.g. Ono (2002), preferences are specified as being additively separable in consumption goods and global environmental quality,[5] and are hence represented by the following log–linear intertemporal utility functions:

$$U_t = \zeta \ln x_t^1 + (1-\zeta)\ln y_t^1 + \beta \left[\zeta \ln x_{t+1}^2 + (1-\zeta)\ln y_{t+1}^2 + \xi \ln E_{t+1}\right], \tag{2}$$

$$U_t^* = \zeta \ln x_t^{*,1} + (1-\zeta)\ln y_t^{*,1} + \beta \left[\zeta \ln x_{t+1}^{*,2} + (1-\zeta)\ln y_{t+1}^{*,2} + \xi^* \ln E_{t+1}\right]. \tag{2*}$$

Consequently, any change in lifetime utility due to an emission permit policy is composed of the utility change caused by the economic consequences of the policy and the utility increase on account of higher global environmental quality in the retirement period.

In maximising intertemporal utility (2), the domestic household is constrained by a budget constraint in each period of life while taking environmental quality as given. Environmental quality is modeled as an international and intergenerational public good that is deteriorated by emissions caused by domestic firms, p_{t+1}, and foreign firms, p_{t+1}^*:

$$E_{t+1} = \mu \bar{E} + (1-\mu)E_t - p_{t+1} - p_{t+1}^*, \tag{3}$$

where $0 < \mu < 1$ measures the speed of the autonomous pollution absorption and $\bar{E}$ is the pre-industrial state of the environment (Jouvet *et al.*, 2005, 1599).

When young, wage income w_t, net of a lump–sum tax τ_t imposed by the national government, is spent on consumption of the domestic and the imported good, with h_t denoting the terms of trade of Home (units of Foreign good per unit of Home good). Furthermore, for transferring income to their retirement period, young households save in terms of domestic capital k_{t+1} and in terms of bonds of Home b_{t+1}^H and of Foreign $b_{t+1}^{*,H}$. From saving, the old household gains interest income, where i_{t+1} and i_{t+1}^* denote the interest rates

[5] According to Weitzman (2010), there is a notable difference in the additive and multiplicative interaction between consumption and environmental quality in utility, with the additive specification favouring more stringent policies.

in Home and Foreign. When old, the household spends interest income and capital on consumption, again for the Home and Foreign good (x_{t+1}^2 and y_{t+1}^2, respectively). Thus, the first period budget constraint for the domestic consumer is given by:

$$x_t^1 + \frac{1}{h_t} y_t^1 + s_t = w_t - \tau_t, \tag{4}$$

where savings are defined as $s_t \equiv k_{t+1} + b_{t+1}^H + (1/h_t)\, b_{t+1}^{*,H}$. The corresponding budget constraint for the foreign consumer is:

$$h_t x_t^{*,1} + y_t^{*,1} + s_t^* = w_t^* - \tau_t^*, \tag{4*}$$

where $s_t^* \equiv k_{t+1}^* + b_{t+1}^{*,F} + h_t b_{t+1}^F$. After taking account of the no–arbitrage condition of the asset market in each country

$$1 + i_t = q_t, \quad 1 + i_t^* = q_t^*, \quad \forall t, \tag{5}$$

the second period budget constraint is given for the domestic consumer by

$$x_{t+1}^2 + \frac{1}{h_{t+1}} y_{t+1}^2 = (1 + i_{t+1}) \left[k_{t+1} + b_{t+1}^H\right] + \left(1 + i_{t+1}^*\right) \frac{1}{h_{t+1}} b_{t+1}^{*,H}, \tag{6}$$

and for the foreign consumer by

$$h_{t+1} x_{t+1}^{*,2} + y_{t+1}^{*,2} = \left(1 + i_{t+1}^*\right) \left(k_{t+1}^* + b_{t+1}^{*,F}\right) + h_{t+1} \left(1 + i_{t+1}\right) b_{t+1}^F. \tag{6*}$$

The government runs a "constant–stock" fiscal policy and thus $b_{t+1} = b_t = b, \forall t$, and $b_{t+1}^* = b_t^* = b^*, \forall t$, respectively (as in Diamond, 1965). Then, market clearing for Home and Foreign bonds demands

$$b = b_t^H + b_t^F, \qquad b^* = b_t^{*,H} + b_t^{*,F}, \qquad \forall t. \tag{7}$$

Since international trade in emission permits is precluded, national permit markets need to clear:

$$p_t = S, \qquad p_t^* = S^*, \qquad \forall t. \tag{8}$$

Then, the budget constraints for Home and Foreign governments require that revenues from tax income and permit trading have to balance with interest payments to the bond holders:

$$\tau_t + e_t S = i_t b, \qquad \tau_t^* + e_t^* S^* = i_t^* b^*, \qquad \forall t. \tag{9}$$

2.3 International market clearing and the terms of trade

Since government bonds are perfectly mobile across Home and Foreign,

$$\left(1+i_{t+1}^{*}\right)\frac{h_t}{h_{t+1}}=\left(1+i_{t+1}\right),\quad \forall t. \tag{10}$$

Clearing of Home's product market requires that domestic supply balances with domestic demand and exports ($x_t^{*,1}+x_t^{*,2}$):

$$x_t=x_t^1+x_t^2+k_{t+1}+x_t^{*,1}+x_t^{*,2},\quad \forall t, \tag{11}$$

and for Foreign, that foreign supply balances with foreign demand and domestic imports ($y_t^1+y_t^2$):

$$y_t^{*}=y_t^{*,1}+y_t^{*,2}+k_{t+1}^{*}+y_t^1+y_t^2,\quad \forall t. \tag{11*}$$

Clearing of the world asset market requires the supply of savings to be equal to the demand for savings (from (4), (4*), and (7)):

$$s_t+\frac{1}{h_t}s_t^{*}=k_{t+1}+b+\frac{1}{h_t}\left[k_{t+1}^{*}+b^{*}\right],\quad \forall t. \tag{12}$$

This equation thus relates the terms of trade movements to capital accumulation and to the levels of domestic and foreign public debt. Rearranging gives the following relationship between Home's terms of trade and the net foreign asset positions of Foreign (ϕ_{t+1}^{*}) and Home (ϕ_{t+1}):

$$h_t=-\frac{k_{t+1}^{*}+b^{*}-s_t^{*}}{k_{t+1}+b-s_t}\equiv-\frac{\phi_{t+1}^{*}}{\phi_{t+1}},\quad \forall t. \tag{12'}$$

Since $h_t>0$, Home being a net creditor ($\phi_{t+1}<0$) implies that Foreign is a net debtor ($\phi_{t+1}^{*}>0$).

2.4 Intertemporal equilibrium dynamics

Acknowledging (8), and substituting for the firm's first order conditions yields an expression for s_t (s_t^{*}) which depends only on k_t (k_t) and exogenously given parameters. By inserting these into the international asset market clearing condition (12), we obtain the following equation of motion:

$$h_t k_{t+1}+k_{t+1}^{*}=h_t\left[\sigma_0\left(k_t\right)^{\alpha_K}-b\left(\sigma\ i_t+1\right)\right]+\sigma_0^{*}\left(k_t^{*}\right)^{\alpha_K}-b^{*}\left(\sigma\ i_t^{*}+1\right), \tag{13}$$

where $\sigma \equiv \beta/(1-\beta)$, $\sigma_0 \equiv (1-\alpha_K)\,\sigma M S^{\alpha_P}$ and $\sigma_0^* \equiv (1-\alpha_K)\,\sigma M\,(S^*)^{\alpha_P}$.

From the national product market clearing conditions (11) and (11*) and the optimal consumptions of domestic and foreign households the combined product market clearing condition results as second law of motion:

$$h_t k_{t+1} - \frac{\zeta}{(1-\zeta)} k_{t+1}^* = h_t M\,(k_t)^{\alpha_K}\,(S)^{\alpha_P} - \frac{\zeta}{(1-\zeta)} M\,(k_t^*)^{\alpha_K}\,(S^*)^{\alpha_P}\,. \tag{14}$$

Considering the no–arbitrage conditions for national asset markets (5), and the firms' first order conditions (1) and (1*) in the international interest parity condition (10), the equation of motion of the terms of trade follows

$$h_{t+1} = h_t \frac{\left(1+i_{t+1}^*\right)}{\left(1+i_{t+1}\right)} = h_t \frac{\left(k_{t+1}^*\right)^{\alpha_K-1}(S^*)^{\alpha_P}}{\left(k_{t+1}\right)^{\alpha_K-1}(S)^{\alpha_P}}. \tag{15}$$

The dynamic system for the (per capita) capital stocks in Home and Foreign (k_{t+1} and k_{t+1}^* respectively) and for the terms of trade (h_t) are thus described by Equations (13), (14), and (15). The autonomous dynamics of environmental quality follows from (3), after acknowledging (8):

$$E_{t+1} = \mu\bar{E} + (1-\mu)E_t - S - S^*. \tag{16}$$

2.5 Characterisation of steady states

Under the presumption of parameter sets which ensure the existence of at least one non–trivial steady state, the discrete dynamical system (13)–(16) determines the steady state $(h, k, k^*, E) = (h_t, k_t, k_t^*, E)\,, \forall t$. Equation (15) gives the following relationship between k and k^*:

$$k^* = \left(\frac{S^*}{S}\right)^{\frac{\alpha_P}{1-\alpha_K}} k. \tag{17}$$

Inserting (17) into (14), yields for the steady state terms of trade:

$$h = \frac{\zeta}{(1-\zeta)} \left(\frac{S^*}{S}\right)^{\frac{\alpha_P}{1-\alpha_K}}. \tag{18}$$

Insert (17) and (18) into (13), to obtain an equation determining k as follows:

$$k + \vartheta(1-\sigma) = M S^{\alpha_P} k^{\alpha_K-1}[\sigma(1-\alpha_K)k - \vartheta\sigma\alpha_K], \tag{19}$$

where $\vartheta \equiv \zeta b + (1-\zeta) b^* (S/S^*)^{\alpha_P/(1-\alpha_K)}$.

Steady state environmental quality depends on domestic and foreign permit volumes and is thus independent of the other dynamic variables:

$$E = \bar{E} - \frac{S + S^*}{\mu}. \tag{20}$$

3 Nationally optimal permit levels

We now turn to the first main focus of the paper—the derivation of the steady state permit levels chosen by each country individually taking the permit decision of the other country as given (Nash equilibrium permit levels).[6] We start by describing the objectives of each government in terms of their underlying choice variables. From now on, we focus on the case that Home is a net foreign creditor country (EU-15) and Foreign a net foreign debtor country (US).

Home's objective is represented by a welfare function $W\left(k(S,S^*), h(S,S^*), S, S^*\right)$ which results from the indirect intertemporal utility function of the young household, evaluated at the steady state: $U(x^1, y^1, x^2, y^2, E)$, and under consideration of steady state equations (17)–(20). Taking Foreign's permit level S^* as given, the Home government chooses its permit level S as to maximise its welfare and the associated FOC defines implicitly Home's reaction function $S^H(S^*)$:[7]

$$\frac{\mathrm{d}W}{\mathrm{d}S} = W_k \frac{\partial k}{\partial S} + W_h \frac{\partial h}{\partial S} + W_S = 0, \tag{21}$$

where

$$W_k = \frac{(1+\beta)}{(w-\tau)} \left[\frac{\partial (w-\tau)}{\partial k} + \frac{s}{(1+i)} \frac{\partial (1+i)}{\partial k} \right], \quad W_h = \frac{(1+\beta)}{(w-\tau)} \left[(1-\zeta) \frac{(w-\tau)}{h} \right],$$
$$W_S = \frac{(1+\beta)}{(w-\tau)} \left[\frac{\partial (w-\tau)}{\partial S} + \frac{s}{(1+i)} \frac{\partial (1+i)}{\partial S} \right] + \frac{\partial U}{\partial E} \frac{\partial E}{\partial S}.$$

[6] Here we assume that the government in Home disregards the preferences of special interest groups and includes only the preferences of young households in its objective function (see Grossman and Helpman, 1994, for the general case).

[7] Our log–linear welfare function ensures the second order conditions for a welfare maximum.

The domestic welfare effects of a change in its permit level comprise thus economic components and an environmental component. A stricter Home permit policy leads to a terms of trade improvement ($\partial h/\partial S < 0$), to reductions in domestic and foreign capital intensities ($\partial k/\partial S > 0$, $\partial k^*/\partial S > 0$), and to an improvement in global environmental quality ($\partial E/\partial S < 0$) (Bednar-Friedl and Farmer, 2010, Prop. 1). Since moreover W_k, W_h and W_S exhibit both positive and negative terms, the net domestic welfare effect is in general ambiguous. When environmental preferences are not too high, the net welfare effect will be negative (Bednar-Friedl and Farmer, 2010, Prop. 2).[8]

Proceeding similarly for Foreign, where the governmental welfare function is represented by $W^*\left(k^*(S,S^*), h(S,S^*), S, S^*\right)$, defines Foreign's reaction function $S^F(S^*)$:

$$\frac{\mathrm{d}W^*}{\mathrm{d}S^*} = W^*_{k^*}\frac{\partial k^*}{\partial S^*} + W^*_h\frac{\partial h}{\partial S^*} + W^*_{S^*} = 0, \tag{22}$$

where

$$W^*_{k^*} = \frac{(1+\beta)}{(w^*-\tau^*)}\left[\frac{\partial(w^*-\tau^*)}{\partial k^*} + \frac{s^*}{(1+i^*)}\frac{\partial(1+i^*)}{\partial k^*}\right], \quad W^*_h = \frac{(1+\beta)}{(w^*-\tau^*)}\left[\zeta\frac{(w^*-\tau^*)}{h}\right],$$

$$W^*_{S^*} = \frac{(1+\beta)}{(w^*-\tau^*)}\left[\frac{\partial(w^*-\tau^*)}{\partial S^*} + \frac{s^*}{(1+i^*)}\frac{\partial(1+i^*)}{\partial S^*}\right] + \frac{\partial U^*}{\partial E}\frac{\partial E}{\partial S^*}.$$

While in general Eqs. (21)–(22) define implicitly the reaction functions of Home and Foreign, the special case of $b = 0$ and $b^* > 0$, such that the Golden Rule ($i = 0$) applies, and equal expenditure share for Home and Foreign goods, $\zeta = 1 - \zeta$, yields explicit reaction functions as derived in the Appendix:

$$S^H(S^*) = \frac{(1+\beta)\alpha_P\zeta}{\beta\zeta(1-\alpha_K) + (1+\beta)\alpha_P\zeta}\left[\mu\bar{E} - S^*\right], \tag{23}$$

$$S^F(S^*) = \mu\bar{E} - \left[1 + \frac{\beta\xi^*(1-\alpha_K)}{(1+\beta)\alpha_P(C+1-\zeta)}\right]S^*, \tag{24}$$

where $C = \left[\sigma(1-\alpha_K) - \alpha_K\right]^2 / \left[\alpha_K - \sigma^2(1-\alpha_K)^2\right] > 0$. Each governments' best-response permit level is thus determined by the combined impact that the induced changes in domestic capital intensity, terms of trade, and environmental quality have on welfare. The Nash equilibrium permit levels ($S^N, S^{*,N}$) are found by solving simultaneously (23) and (24):[9]

[8] This result holds for Home being a net foreign debtor and under dynamic efficiency or for Home being a net foreign creditor and the Golden Rule with an additional parameter restriction.

[9] Note that in the opposite case of Home being a net foreign creditor, this proposition is reversed.

Proposition 1 (Nash equilibrium permit levels) *Suppose that* $\zeta = 1 - \zeta$, $b = 0$ *and* $b^* > 0$ *(Home is a net foreign creditor and Foreign a net foreign debtor) such that* $i = 0$. *Then, the nationally optimal, i.e. Nash, permit levels* $(S^N, S^{*,N})$ *are given by:*

$$S^N = \frac{\xi^*}{\xi} \frac{\zeta}{\zeta + C} S^{*,N}. \tag{25}$$

If moreover $\xi \geq \xi^*$, *then it is optimal for Home to chose a lower permit level than Foreign:* $S^N < S^{*,N}$.

Proof 1 *Equating* (23) *to* (24) *gives* (25). *Knowing from the Appendix that* $C > 0$, *it follows that* $(\zeta/(\zeta + C)) < 1$. *Hence* $\xi \geq \xi^*$ *is sufficient for* $S^N < S^{*,N}$.

The gist of Proposition 1 is that when Home is a net foreign creditor country and does not have a lower preference for the environment than Foreign ($\xi \geq \xi^*$), then Home's optimal choice is a lower permit level than Foreign's. If $\xi > \xi^*$, the difference in environmental preferences reinforces the differences in external balances. The economic intuition for this result becomes clear when considering the case of equal environmental preferences: presuming first that both countries chose equally strong permit levels, $S = S^*$ such that Home's welfare (i.e. the net foreign creditor country's) is maximised, then it follows from comparing (31) and (33) that Foreign's welfare (the net foreign debtor country's) cannot be maximal, i.e. $\partial W^*/\partial S^* > 0$, because of $\phi^* = \zeta b^* > 0$. Since $\partial W^*/\partial S^*$ depends negatively on S^* (see (34) in the Appendix), Foreign's permit level has to be increased to ensure $\partial W^*/\partial S^* = 0$ and hence Foreign's, i.e. the net foreign debtor's, permit level is less stringent than Home's (the net foreign creditor's). A fortiori, this result holds when Home has higher environmental preferences than Foreign.

When on the other hand Home has considerably lower environmental preferences than Foreign, then Home's optimal choice is a higher permit level than Foreign's. In that case, the difference in environmental preferences reverses the difference in external balances: despite Home being a net foreign creditor (which leads to lower domestic economic welfare effects as compared to a net foreign debtor, see Bednar-Friedl and Farmer, 2010), it is optimal for Home to chose a less stringent permit level than Foreign. Thus, the fact of Home being a net foreign creditor country is reflected implicitly in condition (25).

The two possible cases are also illustrated in Figs. 1 and 2, however for the more general case of $0 < b < b^*$ and $i > 0$ (dynamic efficiency).[10] In both figures, the reaction functions of Home and Foreign are negatively sloped, but the resulting Nash equilibria are different: $S^N < S^{*,N}$ in Fig. 1 and the opposite in Fig. 2. In addition to the reaction functions, the welfare indifference curves for Home and Foreign are depicted, evaluated at the Nash equilibrium. In both figures, the first order conditions for national optimality ensure that in the Nash equilibrium, (21) holds for Home and (22) for Foreign. Comparison of Figs. 1 and 2 reveals however that for Home's and Foreign's indifference curves two alternative curvatures are possible: Foreign's curve is either concave or convex to the ordinate, and Home's curve is either concave or convex to the abscissa.

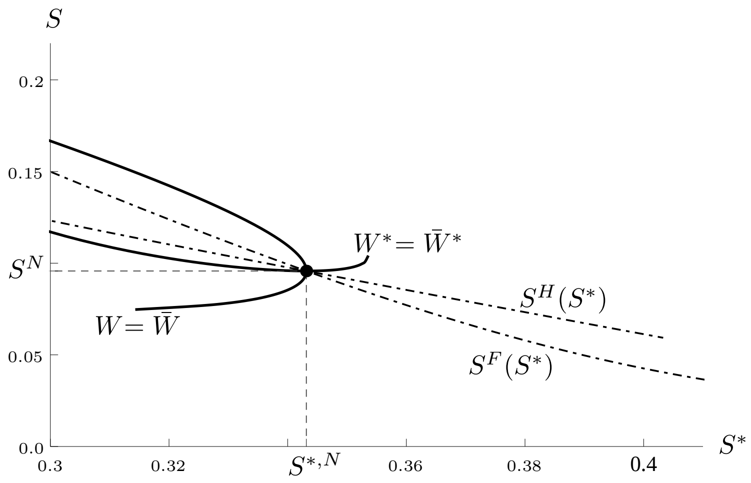

Figure 1: Reaction functions and Nash permit levels when Home is a net foreign creditor and Foreign is a net foreign debtor, and Home has higher environmental preferences than Foreign: $S^N < S^{*,N}$ ($b = 0.15$, $b^* = 0.65$ and $\xi = 0.125$, $\xi^* = 0.1$)

As a final step to the analysis of the Nash equilibria, Proposition 2 ensures their static stability, again for the special case. The generalisation to $0 < b < b^*$ and $i > 0$ is again provided graphically in Figs. 1 and 2: Since Foreign's reaction function cuts Home's reaction function from above in both cases and since both functions are monotonic, the Nash equilibria are stable.

[10]All figures are based on the following common parameter values: $\alpha_K = 0.3$, $\alpha_P = 0.1$, $\beta = 0.8$, $\mu = 0.5$, $\zeta = 0.5$, $\bar{E} = 1$ and $M = 5$. The specific values for b, b^*, ξ, and ξ^* are stated below the respective figures.

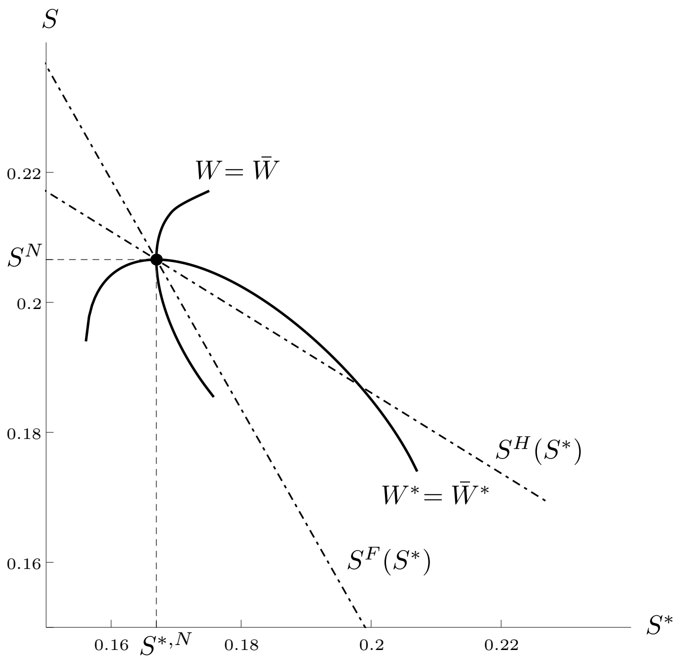

Figure 2: Reaction functions and Nash permit levels when Home is a small net foreign creditor and Foreign is a small net foreign debtor, and Home has lower environmental preferences than Foreign: $S^N > S^{*,N}$ ($b = 0.15$, $b^* = 0.20$ and $\xi = 0.1$, $\xi^* = 0.125$)

Proposition 2 (Static stability of Nash permit levels) *Suppose that* $\zeta = 1 - \zeta$, $b = 0$ *and* $b^* > 0$ *such that* $i = 0$*. Then, the Nash solution of permit levels* $\left(S^N, S^{*,N}\right)$ *is statically stable.*

Proof 2 *Since according to* (23) *and* (24) $S^F(0) = \mu\bar{E} > S^H(0)$ *and the slope of both reaction functions is negative* $((S^F)' < 0, (S^H)' < 0)$, $\left(S^N, S^{*,N}\right)$ *is statically stable.*

4 Internationally optimal permit policies

The international real interest parity condition (15) and the fact that households care for environmental quality suggest that nationally optimal permit levels are also optimal from an international perspective (as in Ogawa and Wildasin, 2009, in another context). To evaluate this hypothesis within our modeling framework we first characterise in this section internationally optimal permit policies and then investigate whether nationally optimal policies are optimal also from an international perspective.

To derive the conditions for internationally optimal permit policies, assume that Home maximises welfare by choosing domestic and foreign permit levels under the constraint that Foreign achieves welfare at the level of the nationally optimal solution:

$$\max_{\{S,S^*\}} W\left(k(S,S^*),h(S,S^*),S,S^*\right), \tag{26}$$
subject to
$$W^*\left(k^*(S,S^*),h(S,S^*),S,S^*\right)=\bar{W}^*.$$

This yields the following first order condition requiring that the slopes of the welfare indifference curves (marginal rates of substitution) are equalised across countries:

$$\left.\frac{\mathrm{d}S}{\mathrm{d}S^*}\right|_{\mathrm{d}W=0}=\left.\frac{\mathrm{d}S}{\mathrm{d}S^*}\right|_{\mathrm{d}W^*=0}, \tag{27}$$

where

$$-\left.\frac{\mathrm{d}S}{\mathrm{d}S^*}\right|_{\mathrm{d}W=0}\equiv \mathrm{MRS}=\frac{\mathrm{d}W/\mathrm{d}S^*}{\mathrm{d}W/\mathrm{d}S}=\frac{W_k\frac{\mathrm{d}k}{\mathrm{d}S^*}+W_h\frac{\mathrm{d}h}{\mathrm{d}S^*}+W_{S^*}}{W_k\frac{\mathrm{d}k}{\mathrm{d}S}+W_h\frac{\mathrm{d}h}{\mathrm{d}S}+W_S}, \tag{28}$$

$$-\left.\frac{\mathrm{d}S}{\mathrm{d}S^*}\right|_{\mathrm{d}W^*=0}\equiv \mathrm{MRS}^*=\frac{\mathrm{d}W^*/\mathrm{d}S^*}{\mathrm{d}W^*/\mathrm{d}S}=\frac{W^*_{k^*}\frac{\mathrm{d}k^*}{\mathrm{d}S^*}+W^*_h\frac{\mathrm{d}h}{\mathrm{d}S^*}+W^*_{S^*}}{W^*_{k^*}\frac{\mathrm{d}k^*}{\mathrm{d}S}+W^*_h\frac{\mathrm{d}h}{\mathrm{d}S}+W^*_S}, \tag{29}$$

and moreover

$$W_{S^*}=\frac{\partial U}{\partial E}\frac{\partial E}{\partial S^*},\quad W^*_S=\frac{\partial U^*}{\partial E}\frac{\partial E}{\partial S}.$$

A major difference compared to the first order conditions for nationally optimal permit levels presented above is that now also the spillover effects of the domestic policy on the other country are taken account of, namely $\mathrm{d}W/\mathrm{d}S^*$ and $\mathrm{d}W^*/\mathrm{d}S$.

It is straightforward to see that the Nash equilibrium permit levels, as defined by the reaction functions, do not fulfill the condition for international optimality.

Proposition 3 (International non–optimality of nationally optimal permit levels) *Nationally optimal permit levels resulting from* (21) *and* (22) *are internationally non–optimal (Pareto inefficient).*

Proof 3 *Suppose that* $\mathrm{d}W/\mathrm{d}S^*\neq 0$ *and* $\mathrm{d}W^*/\mathrm{d}S\neq 0$. *Since for national optimality the denominator in* (28) *is zero according to* (23), $\mathrm{d}S/\mathrm{d}S^*|_{\mathrm{d}W=0}=\pm\infty$. *On the other hand,* (24) *implies that* $\mathrm{d}S/\mathrm{d}S^*|_{\mathrm{d}W=0}=0$ *because the numerator is zero. Hence,* (27) *is violated by* $\left(S^N,S^{*,N}\right)$.

Thus, in contrast to the findings of Ogawa and Wildasin (2009), in our model with endogenous capital formation and thus endogenous determination of world interest rates, and environmental quality as a global (instead of a local) public good, strategic dependence of permit levels across countries emerges. Due to this strategic dependence via capital stocks and terms of trade (see (21) and (22)), nationally optimally policies depend on the policy choice of the other country (see reaction functions (23) and (24)) and are hence not internationally optimal.

Having established that the Nash permit levels are internationally non–optimal, the question arises as to how they deviate from the internationally optimal permit levels. To answer this question, we proceed in two steps. The first is to establish the prerequisite for a Pareto improvement: according to (26), Foreign's welfare has to be as high as $\bar{W}^*$, i.e. the welfare level achieved at the Nash solution. Moreover, Home's welfare has to increase relative to the Nash solution. This leads to three possible outcomes, as summarised by the following proposition:

Proposition 4 (Pareto improving permit levels) *Suppose Home is a net foreign creditor and Foreign a net foreign debtor such that* $0 \leq b < b^*$*. Then, three cases can emerge with respect to the Pareto efficient permit levels* $\left(S^{PE}, S^{*,PE}\right)$*:*

(i) When at $\left(S^{N}, S^{*,N}\right)$ $\mathrm{d}W/\mathrm{d}S^* < 0$ *and* $\mathrm{dMRS}^*/\mathrm{d}S^* < 0$*, then* $S^{PE} > S^N$ *and* $S^{*,PE} < S^{*,N}$*.*

(ii) When at $\left(S^{N}, S^{*,N}\right)$ $\mathrm{d}W/\mathrm{d}S^* > 0$ *and* $\mathrm{dMRS}^*/\mathrm{d}S^* > 0$*, then* $S^{PE} < S^N$ *and* $S^{*,PE} > S^{*,N}$*.*

(iii) When at $\left(S^{N}, S^{*,N}\right)$ $\mathrm{d}W/\mathrm{d}S^* < 0$ *and* $\mathrm{dMRS}^*/\mathrm{d}S^* > 0$*, then* $S^{PE} < S^N$ *and* $S^{*,PE} < S^{*,N}$*.*

Proof 4 *Since* (22) *holds at the Nash equilibrium, the total derivative of Foreign's marginal rate of substitution with respect to* S^* *is given by*

$$\frac{\mathrm{dMRS}^*}{\mathrm{d}S^*} = \frac{\mathrm{d}^2 W^*/\mathrm{d}(S^*)^2}{\mathrm{d}W^*/\mathrm{d}S}.$$

Moreover, to ensure that Home's welfare is improved by the policy, it is required that

$$\frac{\mathrm{d}W}{\mathrm{d}S}\mathrm{d}S + \frac{\mathrm{d}W}{\mathrm{d}S^*}\mathrm{d}S^* > 0.$$

But at the Nash equilibrium, $\mathrm{d}W/\mathrm{d}S = 0$ *because of* (21). *Thus, for a welfare improvement it is necessary that* $-(\mathrm{d}W/\mathrm{d}S^*)\mathrm{d}S^* > 0$. *Assuming first that* $\mathrm{d}W/\mathrm{d}S^* < 0$ *implies that* $\mathrm{d}S^* < 0$. *If moreover* $\mathrm{dMRS}^*/\mathrm{d}S^* < 0$, *then* $\mathrm{d}S > 0$ *and case (i) follows. If instead* $\mathrm{dMRS}^*/\mathrm{d}S^* > 0$, *then* $\mathrm{d}S < 0$ *and case (iii) follows. Case (ii) results as the combination of cases (i) and (iii):* $\mathrm{d}W/\mathrm{d}S^* > 0$ *implies that* $\mathrm{d}S^* > 0$. *If moreover* $\mathrm{dMRS}^*/\mathrm{d}S^* > 0$, *then* $\mathrm{d}S < 0$.

The main finding of Proposition 4 is that a Pareto improvement is characterised either by counteracting permit level adjustment (cases (i) and (ii)) or by matching permit level adjustment (case (iii)), such that either one country needs to reduce its permit level relative to its Nash level and the other needs to increase its level, or both countries reduce their permit level in comparison to the Nash levels. In case (i), Home's welfare is increased by a decrease in S^* such that Home's welfare can rise even when increasing S. In case (ii), Home's welfare is affected positively by an increase in S^*, but S needs to fall in order to hold Foreign's welfare at its Nash level. This different adjustment in cases (i) and (ii) is moreover the result of the curvature of Foreign's welfare indifference curve: while in (i) it is convex to the ordinate, it is concave in case (ii). Finally, case (iii) results when Home can benefit from a reduction in both permit levels while Foreign's welfare remains unaffected (at the Nash welfare level). Regarding global environmental quality, the result is in general ambiguous (in cases (i) and (ii)) while an environmental improvement results in (iii).

The final step of this analysis consists of determining which of these three cases emerge under different combinations of external balances and environmental preferences:

Proposition 5 (Foreign asset position, environmental preferences and permit levels) *Suppose that* $\zeta = 1 - \zeta$, $b = 0$ *and* $b^* > 0$ *such that* $i = 0$. *Depending on the relative strength of environmental preferences, two cases can be distinguished:*

(i) When $\xi > \xi^*$, *then* $S^{PE} > S^N$ *and* $S^{*,PE} < S^{*,N}$.

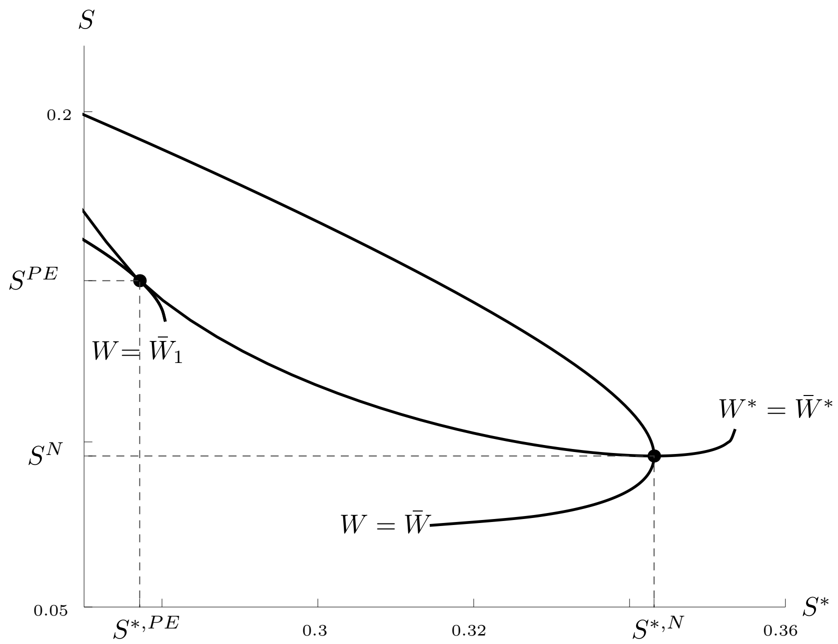

Figure 3: Counteracting permit level adjustments ($S^N < S^{PE}$ and $S^{*,N} > S^{*,PE}$) ($b = 0.15$, $b^* = 0.65$ and $\xi = 0.125$, $\xi^* = 0.1$)

(ii) When $\xi << \xi^*$, then $S^{PE} < S^N$ and $S^{*,PE} > S^{*,N}$.

Proof 5 *The proof requires to sign* $\mathrm{d}W/\mathrm{d}S^*$ *and* $\mathrm{dMRS}^*/\mathrm{d}S^*$ *at the Nash equilibrium when* $\zeta = 1 - \zeta$, $b = 0$ *and* $b^* > 0$ *such that* $i = 0$*. For the derivations of* $\mathrm{d}W/\mathrm{d}S$, $\mathrm{d}W^*/\mathrm{d}S^*$, *and* $\mathrm{d}W/\mathrm{d}S^*$ *under these conditions, see the Appendix. As a consequence,*

$$\frac{\mathrm{dMRS}^*}{\mathrm{d}S^*} = \frac{\dfrac{-\alpha_P(1+\beta)(1-\zeta+C)}{(S^*)^2(1-\alpha_K)} - \dfrac{\beta\xi^*}{[\mu\bar{E} - (S+S^*)]^2}}{\dfrac{\beta(\xi-\xi^*)}{\mu\bar{E} - (S+S^*)}} \gtrless 0 \Longleftrightarrow \xi \lesseqgtr \xi^*.$$

When $\xi > \xi^*$, *according to* (35) *in the Appendix we have* $\mathrm{d}W/\mathrm{d}S^* < 0$ *and* $\mathrm{dMRS}^*/\mathrm{d}S^* < 0$*. If instead* $\xi < \xi^*$, *we certainly have* $\mathrm{dMRS}^*/\mathrm{d}S^* > 0$ *and if moreover* ξ *is considerably smaller than* ξ^*, *then* $\mathrm{d}W/\mathrm{d}S^* > 0$.

Starting with our Golden Rule case, we find in Proposition 5 that only cases (i) and (ii) are possible, but not (iii). Thus, when the Golden Rule applies at the Nash equilibrium and Home is a net foreign creditor country, higher environmental preferences in Home imply that Foreign has to reduce its permit level compared to Nash, while Home needs to increase its permit level for Pareto efficiency. Recall however from Proposition 1 that the

Nash equilibrium permit level is in this case lower for Home than for Foreign such that the increase in Home's permit level does not necessarily imply that Home's Pareto efficient permit level is higher than Foreign's. Moreover, case (i) of Proposition 5 is fairly general and holds also in cases when Home's environmental preferences are smaller than Foreign's, as long as this difference in environmental preferences is insufficient to reverse the effect of the positive external balance. When on the other hand Home'e environmental preferences are considerably smaller than Foreign's, then the effect of Home's positive external balance is reversed such that Home needs to reduce its permit level (which in the Nash equilibrium is in this case above Foreign's, see Proposition 1). Extensive numerical analysis suggests that case (iii) of Proposition 4 cannot emerge when the Golden Rule holds in the Nash equilibrium, since the Golden Rule requires that external balances (i.e. b^*) are small.

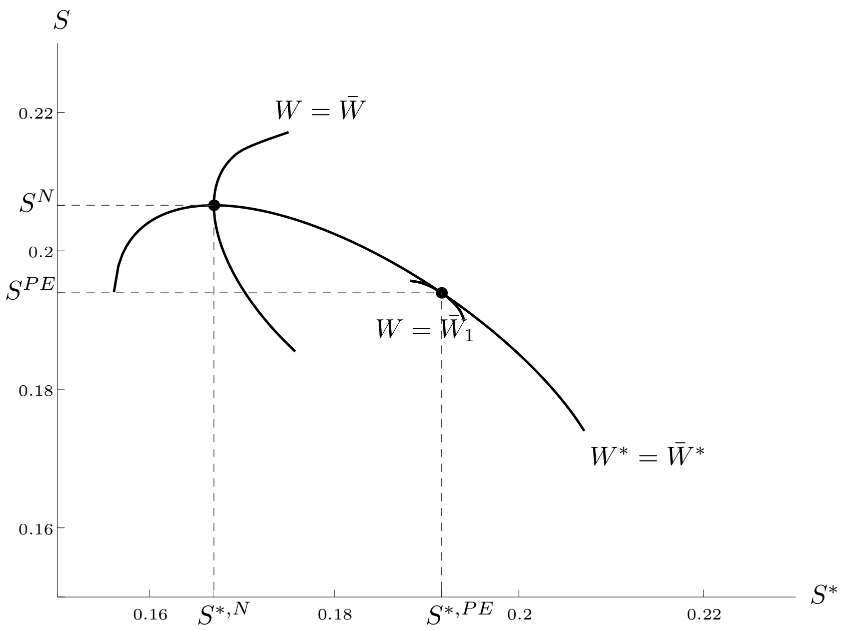

Figure 4: Counteracting permit level adjustments ($S^N > S^{PE}$ and $S^{*,N} < S^{*,PE}$) ($b = 0.15$, $b^* = 0.20$ and $\xi = 0.1$, $\xi^* = 0.125$)

To generalise our results beyond the Golden Rule, we use again graphical analysis based on numerical parameter values. Fig. 3 illustrates case (i) of Proposition 4 and Fig. 4 illustrates case (ii), already discussed above for the Golden Rule case. In the general case of dynamic efficiency, i.e. $0 \leq b < b^*$ chosen such that $i > 0$ result, also case (iii) of Proposition 4 can emerge, as depicted in Fig. 5. One prerequisite for this case to result is that Foreign is a large net foreign debtor and Home is a large net foreign creditor such that differences

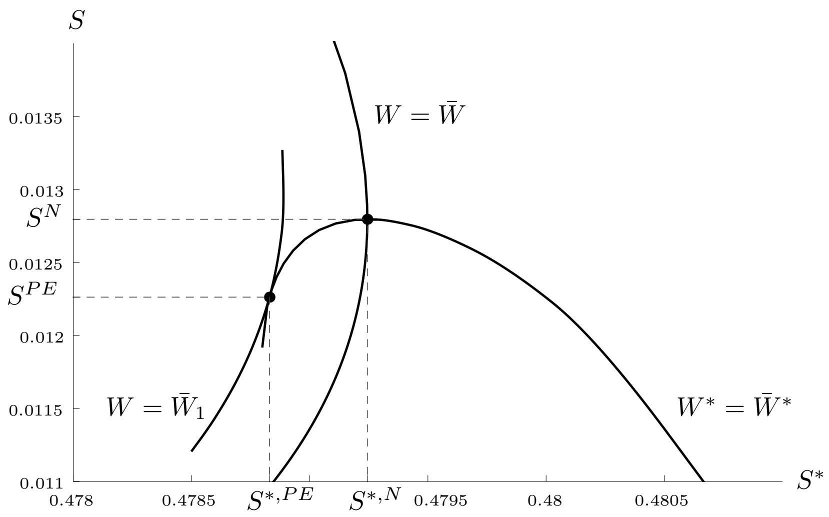

Figure 5: Matching permit level adjustments ($S^N > S^{PE}$ and $S^{*,N} > S^{*,PE}$) ($b = 0$, $b^* = 0.89$ and $\xi = 0.1$, $\xi^* = 0.125$)

in external balances are huge, and environmental preferences are higher in Foreign than in Home. When instead differences in external balances are not too large as compared to differences in environmental preferences, case (i) results (Fig. 3). On the contrary, when differences in environmental preferences dominate, such that Foreign has considerably higher environmental preferences than Home, while differences in external balances are quite small, case (ii) results (Fig. 4). Comparing the characteristics of these three cases to the EU-15 (Home) and the US (Foreign), we have argued in the introduction that $b < b^*$ and $\xi > \xi^*$ such that case (i) best describes this situation—according to Proposition 1, the EU-15 is indeed likely to implement a stricter permit level as nationally optimal policy than the US. Regarding the direction for Pareto efficiency improvements, the US need to reduce its permit level and the EU-15 would need to raise its level. A possible explanation why the EU-15 would according to our analysis set a lower permit level than is Pareto efficient is driven by the differences in environmental preferences (which induce the EU to partly compensate for the laxer Nash permit level in the US) and also by the economic welfare costs caused by permit reductions which are lower for net foreign creditor countries than for net foreign debtor countries.

5 Conclusions

This paper analyses nationally and internationally optimal strategies for national permit trading systems pursued by each country in a two–country, two–good overlapping generations model where national governments maximise the sum of steady state economic and environmental welfare. Concentrating on the case that Home is a net foreign creditor country and Foreign is a net foreign debtor country, we find three cases.

When Home has higher environmental preferences than Foreign (case i), it is nationally optimal for Home to set a stricter permit level than Foreign. Moreover, Pareto efficiency requires that Foreign reduces its permit level while Home increases its level. When Home has considerably lower environmental preferences but the difference in external balances is not too large (case ii), it is nationally optimal for Home to set a laxer permit level than Foreign. For Pareto efficiency, Home needs to reduce its permit level while Foreign increases its permit level. When Home has lower environmental preferences and the difference in external balances is substantial (case iii), Home's nationally optimal permit level is, as in case (i), stricter than in Foreign. But for Pareto efficiency Home needs to reduce its permit level further along with Foreign.

Regarding the empirical relevance of our findings, stylised facts suggest that the EU-15 is a net foreign creditor country with (slightly) higher environmental preferences than the net foreign debtor country US. This characterisation corresponds to case (i). Given the high uncertainty involved when estimating environmental preferences (for a discussion, see Weitzman, 2010), also case (iii) could reflect real world circumstances, except for the large difference in external balances required which does not conform to stylised facts on external balances. Case (ii) is certainly not a realistic description of reality and therefore of theoretical relevance only.

Coming back to three questions raised in the introduction, we find that a positive external balance decreases nationally optimal permit levels, and that the same holds for higher domestic environmental preferences. Secondly, we find that nationally optimal emission permit levels are not internationally optimal (Pareto efficient). This result can be traced back to the fact that national governments do not consider the spillover effects of their domestic permit policy on endogenous capital accumulation abroad. As summarised above, the direction and strength of differences in external balance and environmental preferences are decisive for internationally optimal permit levels to require either a permit level adjustment in opposite directions or a matched permit level reduction relative to Nash levels.

An obvious follow–up question is how nationally optimally permit policies can be improved in order to achieve international optimality when binding multilateral agreements among sovereign nations are out of reach. Whether the linking of national permit systems or intertemporal flexibility brings about international optimality is left to future research. A second possible direction for future research is to endogenise government debt levels and investigate whether this setting still leads to similar results as in the present form with exogenous debt levels. Finally, countries do not only differ with respect to their external balances and environmental preferences, other important differences for the present research question are differences in technologies, particularly in regard to emissions.

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A Derivation of reaction functions and cross welfare effects

In the following we focus on the case that $b = 0$ and b^* such that the Golden Rule ($i = 0$) applies and assume that $\zeta = 1 - \zeta$.

Starting from (21), we know from Bednar-Friedl and Farmer (2010) that $\mathrm{d}W/\mathrm{d}S$ can be simplified to:

$$\frac{\mathrm{d}W}{\mathrm{d}S} = \frac{\alpha_P(1+\beta)}{S(w-\tau)}\left\{\gamma\left[i(k+b)+\phi\right] + \zeta\frac{(1+i)k}{\alpha_K} + (1-\zeta)\frac{i\,b}{(1-\alpha_K)}\right\} - \frac{\beta\xi}{\mu\bar{E}-(S+S^*)}. \tag{30}$$

But $b = 0$ implies $\gamma = 0$ and for $i = 0$, $(w - \tau) = [(1 - \alpha_K)/\alpha_K]k$, such that

$$\frac{\mathrm{d}W}{\mathrm{d}S} = \zeta \frac{\alpha_P(1+\beta)}{S(1-\alpha_K)} - \frac{\beta\xi}{\mu\bar{E} - (S+S^*)}. \tag{31}$$

Setting (31) equal to zero and solving for S yields Home's reaction function (23).

To derive (24), we start from (21) and simplify according to Bednar-Friedl and Farmer (2010) but considering that $\xi \neq \xi^*$:

$$\frac{\mathrm{d}W^*}{\mathrm{d}S^*} = \frac{\alpha_P(1+\beta)}{S^*(w^*-\tau^*)} \left\{ \gamma^* \left[i(k^*+b^*) + \phi^* \right] + (1-\zeta)\frac{(1+i)k^*}{\alpha_K} + \right. \\ \left. + \zeta \frac{i\ b^*}{(1-\alpha_K)} \right\} - \frac{\beta\xi^*}{\mu\bar{E} - (S+S^*)}, \tag{32}$$

which for $i = 0$, after acknowledging that $w^* - \tau^* = [(1 - \alpha_K)/\alpha_K]k^*$, collapses to

$$\frac{\mathrm{d}W^*}{\mathrm{d}S^*} = \frac{\alpha_P(1+\beta)\alpha_K}{S^*(1-\alpha_K)k^*} \left\{ \gamma^*\phi^* + (1-\zeta)\frac{k^*}{\alpha_K} \right\} - \frac{\beta\xi^*}{\mu\bar{E} - (S+S^*)}. \tag{33}$$

From Bednar-Friedl *et al.* (2010, 39) we know for $\zeta = 1 - \zeta$ that $[\alpha_K\gamma^*\phi^*]/k^* = [\sigma(1 - \alpha_K) - \alpha_K]^2/[\alpha_K - \sigma^2(1 - \alpha_K)^2] > 0$. Defining this expression as C, we obtain

$$\frac{\mathrm{d}W^*}{\mathrm{d}S^*} = \frac{\alpha_P(1+\beta)}{S^*(1-\alpha_K)}(C + 1 - \zeta) - \frac{\beta\xi^*}{\mu\bar{E} - (S+S^*)}. \tag{34}$$

Setting (34) equal to zero and solving for S yields Foreign's reaction function (24).

For international optimality, we also require the cross welfare effects of changes in S and S^*. Proceeding as for (31) and (34), but additionally acknowledging $S = S^H(S^*)$ for Home's welfare effect and $S = S^F(S^*)$ for Foreign's, gives for $\mathrm{d}W/\mathrm{d}S^*$ and $\mathrm{d}W^*/\mathrm{d}S$:

$$\frac{\mathrm{d}W}{\mathrm{d}S^*} = \frac{\beta\left[(1-\zeta)(\xi-\xi^*) - C(\xi+\xi^*)\right]}{(C+1-\zeta)\left[\mu\bar{E} - (S+S^*)\right]}, \tag{35}$$

$$\frac{\mathrm{d}W^*}{\mathrm{d}S} = \frac{\beta(\xi-\xi^*)}{\left[\mu\bar{E} - (S+S^*)\right]}. \tag{36}$$