The Effects of Trade Sanctions in International Environmental Agreements

Modeling the Influence of Tariffs on Coalition Formation in a Dynamic Climate Game

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Abstract

The prospects for cooperation on climate protection beyond 2012 are uncertain. Thus policy instruments which foster participation in International Environmental Agreements (IEA) are in demand. Among the instruments under discussion are trade sanctions. Multi-region optimal growth models are a state of the art tool for their assessment, but introducing trade sanctions distorts the market equilibrium making it difficult to compute numerically. We introduce trade and trade sanctions into a model of coalition stability to assess the scope of trade sanctions to support an IEA. Trade is modeled as an exchange of differentiated goods that are imperfect substitutes across countries (Armington goods), and coalitions are granted the option to impose tariffs on imports from non-members. We solve the model numerically using a refined version of Negishi´s (1960) basic algorithm. We then apply the model to analyze the influence of tariffs on international cooperation. The model suggests that there is indeed significant potential to raise participation through trade sanctions, even if goods from different countries are nearly perfect substitutes. Furthermore we investigate the effect of trade sanctions on global welfare, environmental effectiveness and the credibility of the tariff mechanism.

1. Introduction and Motivation

Integrated Assessment Models (IAMs)–which combine elements of the economic, the energy and the climate system–have become an indispensable formal tool in the realm of climate policy analysis. There are numerous examples, ranging from Nordhaus' (1992) seminal DICE model to the latest generation of regionalized models featuring a high level of sectoral and technological detail.[1]

A prominent class within the IAM family consists of optimal growth models; these build on a tradition going back to Ramsey (1928), and view accumulation and economic growth as driven by agents' intertemporally optimized investment decisions. Examples include the RICE - DICE family of models (Nordhaus 1992, Nordhaus and Yang 1996), and its modifications such as FEEM-RICE (Bosetti et al 2004) or ENTICE (Popp 2004), as well as the MIND (Edenhofer et al. 2005) and DEMETER (Gerlagh 2006) models.

The usefulness of intertemporal optimization is justified mainly by two aspects: First, Edenhofer et al. (2006) argue that this framework is appropriate whenever the research question requires an economic model to be run over long time horizons and to capture structural changes. Indeed, inertia in the climate system requires time horizons even longer than a century. Second, Turnovsky (1997, 3ff), from a purely economic point of view, backs the intertemporal utility maximization of a

1 See, for example, Kypreos and Bahn (2003), Barker et al. (2006), Crassous, Hourcade and Sassi (2006), Bosetti et al. (2006).

representative agent as the preferred way to give macroeconomic models a firm micro-foundation and make them suitable for welfare analysis. Although critics point to the fact that assumptions such as perfect foresight and strict rationality are actually at odds with reality, results from such models retain their usefulness (at least) in terms of a first-best benchmark.

To come closer to the political reality of a world consisting of self-interested and sovereign nation states, optimal growth models, just like other IAMs, have over time passed from a uni-regional world[2] representation to a decentralized multiregional[3] formulation. Unfortunately, even the sole introduction of emissions trade comes at the cost of a substantial aggravation of the numerics required to compute market equilibria. The calculation of trade flows and price vectors would in principle be straightforward with Negishi's (1960) algorithm. But in the presence of an externality such as the climate feedback, an appropriate modification of the algorithm is required.[4] The additional effort is, of course, justified by the need to estimate the regional distribution of climate damages and mitigation costs, as well as by the new possibility to compute scenarios in which only a group of nations–a 'climate coalition'–decides to cooperate on climate change.

In our work we follow the multiregional modeling approach and formally extend it in two ways: first, international trade in goods is introduced by dropping the common assumption[5] that all countries produce a common generic good; instead we assume countries to be completely specialized. This approach is often encountered[6] in CGE modeling and referred to as Armington assumption/elasticity. It constitutes a necessary step if one wants to capture international cost spillovers from mitigation policies.[7] Second, we introduce another feature that is incompatible with the basic Negishi approach, namely a tax distortion in form of a punitive tariff duty.

The first part of the paper emphasizes the formal aspects of solving such a model structure for a market equilibrium. We present an algorithm that partially draws on work by Kehoe et al. (1992) and Leimbach and Edenhofer (2007), and give quantitative evidence that indeed a market equilibrium is obtained.

To demonstrate the usefulness of the model set-up, an application to a current issue in climate policy is presented in the second part of the

2 E.g. DICE (Nordhaus 1992) and MIND (Edenhofer et al. 2005).
3 E.g. RICE (Nordhaus and Yang 1996) and WITCH (Bosetti et al. 2006).
4 Implementing trade in these models is challenging (Nordhaus and Yang 1996, Eyckmans and Finus 2006). Nordhaus and Yang (1996) mention that “a major cause of the long gestation period of this research has been the difficulty in finding a satisfactory algorithm for solving the intertemporal general equilibrium”.
5 E.g. in the RICE (Nordhaus and Yang 1996) and WITCH (Bosetti et al. 2006) models.
6 E.g. Bernstein et al. (1999), Kemfert (2002).
7 In models without trade, one country's carbon constraint bears no economic consequences for other countries. This seems contradictory when thinking of shifts in competitive advantage and specialization ('carbon leakage'), as well as of the negative consequences for some countries if fossil fuel demand plunges.

paper. Namely, we analyze the scope for regional cooperation–that is the viability of a 'climate coalition'–and investigate whether tariffs can help to increase participation in such a coalition.

Both model extensions are needed for this inquiry to be feasible within the framework of optimal growth. Moreover, the applied part of our paper seems timely in view of the currently meager prospects for full international cooperation after the expiry of the Kyoto Protocol in 2012. Indeed, a lively debate has emerged on the scope for regional cooperation, and various supportive policy instruments have been brought up in the literature, such as R&D protocols (Barrett 2003, Carraro et al. 2002), a technology fund (Benedick 2001), a Marshall Plan (Schelling 2002), and, last but not least, trade sanctions (e.g. Aldy, Orszag and Stiglitz 2001).

The use of trade restricting tariff duties has been proposed in the form of energy or CO_2 border tax adjustments, with the double objective to deter free-riding and to ease the loss of competitiveness for coalition members. The debate is mainly focused on the question of whether tariffs are feasible under legal (Biermann and Brohm 2005) and implementation (Ismer and Neuhoff 2007) aspects. Another question is whether their employment would be credible, given that orthodox economic theory suggests that the distortionary effects of tariffs would be welfare depressing for all parties.

More specifically, Stiglitz (2006) proposes to raise participation in a climate treaty by imposing trade sanctions against non-signatories. He argues that this is possible and even required in the legal framework of the World Trade Organization (WTO): products from countries that allow unconstrained emissions are implicitly subsidized which warrants to prohibit or tariff the import of such products. Perez (2005) gives a detailed analysis of the legal implications of such a proposal concluding that recent precedents (the so-called "shrimp decision") suggest that the WTO will not interfere with such tariffs. Similar to these trade sanctions, Nordhaus (1998) proposes border tax adjustments to enforce compliance with harmonized carbon taxes.

The effects of trade sanctions on coalition formation have also been analyzed within formal models (Barrett 1997, Finus and Rundshagen 2000), albeit to lesser extent. As mentioned before, the widely used optimal growth models do not naturally accommodate trade in goods (other than emissions trade), and are therefore normally unsuitable for an analysis of the effects of tariffs. Thus, existing formal studies of trade sanctions and international cooperation either utilize a static modeling framework (Barrett 1997) or Computable General Equilibrium (CGE) models (Kemfert 2004).

For the purpose of this paper, we apply the model in stylized–that is not empirically calibrated–form in order to explore the scope for tariffs in international cooperation. We find that under the assumption of full specialization and price- as well as tariff-taking behavior of all countries, the imposition of tariffs on non-coalition members unequivocally raises the scope for international cooperation. However, the coalition's welfare gains start to decline once the tariffs go beyond a certain threshold, and–at a still higher level–tariffs actually become welfare decreasing and thus lose credibility. We interpret the observed effects as the consequence of a particular market structure: when all countries are monopolistic suppliers, but must behave as price-takers, the tariff constitutes an indirect price setting mechanism, which helps coalition countries to take advantage of their market power. However, the benefits from this price increase start to vanish once it exceeds the optimal monopoly price.

Although we employ the model and the algorithm in an exemplary way in order to explore the scope for tariffs in coalition formation, it can be easily extended to other research questions, e.g. to investigate the effects of differentiated border tax adjustments (BTA) on coalition formation, or to analyse the long-term structural effects of different (optimal, non-optimal) carbon taxes.

The remaining part of the paper is organized as follows: The next section presents the model, Section 3 explains the algorithm. In Section 4, we discuss its application to coalition stability in a model with import tariffs, and Section 5 concludes.

2. Model Structure

We begin by stating the problem: we introduce a multi-actor growth model with climate change damages and tariffs on trade flows.

2.1 Preferences

Each region *i* is modeled following Ramsey (1928), i.e. the maximization of discounted utility endogenously determines the intertemporal consumption-investment pattern.

$$\text{welfare}_i = \int_0^\infty e^{-\rho\, t}\; l_{it}\, U(c_{it}/l_{it})\ \text{dt} \tag{1}$$

Instantaneous utility *U* is an increasing and concave function of per capita consumption *c/l.* It is weighted with the region's total population *l* and discounted with a rate of pure time preference ρ.

In a world with international trade between uniquely specialized countries, utility depends on the consumption of both domestic c^{dom} and foreign goods c^{for}, which are combined into a so-called Armington aggregate by a CES function with an elasticity determined by the parameter ρ^A.

$$c_{it} = \left[s^{dom} (c_{it}^{dom})^{\rho^A} + \sum_{j \neq i} s_j^{for}\, (c_{ijt}^{for})^{\rho^A} \right]^{(1/\rho^A)} \tag{2}$$

Share parameters s^{dom} and s_j^{for} characterize the preference for domestic or foreign goods and add up to one.

2.2 Technology

We assume a macroeconomic production function *F* of the Cobb-

Douglas form that depends on two input factors, capital stock *k* and labor supply *l*.

$$F(k_{it}, l_{it}) = (k_{it})^{\beta}\,(a_{it}\,l_{it})^{(1-\beta)} \tag{3}$$

Hence, technology is constant-returns-to-scale and with decreasing marginal productivity in both factors. Labor productivity *a* grows exogenously at the constant rate *gr*.

While labor is given exogenously, capital can be accumulated by investment:

$$\dot{k}_{it} = in_{it} \tag{3}$$

2.3 Climate dynamics

Greenhouse gas emissions *e* are generated as a byproduct of production. The emission intensity decreases autonomously at 1 percent per year (*ei*), and may be reduced by investments *im* in abatement capital *km*. Parameter *iekm* determines the investments' efficiency.

$$e_{it} = \sigma_{it}\,ei_t\,y_{it} \tag{4}$$

$$\sigma_{it} = (1 + km_{it})^{-\psi} \tag{5}$$

$$\dot{km}_{it} = iekm\;im_{it} \tag{6}$$

The climate system is represented in a stylized way based on Petschel-Held et al. (1999). The total stock of atmospheric greenhouse gases *ce* grows due to the instantaneous emissions of all countries

$$\tfrac{d}{dt}ce_t = \textstyle\sum_j e_{jt} \tag{7}$$

and is linked to the greenhouse gas concentration *conc* according to

$$\tfrac{d}{dt}conc_t = B\,ce + \beta^P \textstyle\sum_j e_{jt} - \sigma^P(conc_t - conc_0) \tag{8}$$

The concentration, in turn, determines the change of global mean temperature *temp* by

$$.\tfrac{d}{dt}temp_t = \mu \log(conc_t/conc_0) - \alpha^P(temp_t - temp_0) \tag{9}$$

Similar to Nordhaus and Yang (1996), temperature change induces climate change damages, destroying a fraction $1-\Omega$ of economic output:

$$\Omega_{it} = 1/(1 + dam1_i(temp_t)^{dam2_i}) \tag{10}$$

$$y_{it} = \Omega_{it}\,F(k_{it}, l_{it}) \tag{11}$$

2.4 Trade and tariffs

We impose an intertemporal budget constraint enforcing that export value and import value are ultimately balanced.

$$\int_0^\infty \textstyle\sum_{j\neq i} p^m_{ijt}\,m_{ijt}\;\mathrm{dt} = \int_0^\infty \sum_{j\neq i} p^x_{ijt}\,x_{ijt}\;\mathrm{dt} \tag{13}$$

Imports received by *i* from *j* are denoteed by m_{ij}, exports from *i* to *j* by x_{ij}. Naturally, imports and exports that describe the same trade flow must be the same, hence $m_{ijt} = x_{jit}$. Imports become foreign consumption goods after import tariffs–if any–have been deducted in the form of iceberg costs.

$$c_{ijt}^{for} = (1 - \tau_i)\, m_{ijt} \tag{14}$$

$$tr_{ijt} = \tau_{ij}\, m_{ijt} \tag{15}$$

Tariff revenues *tr* are recycled without the consumer realizing the origin of the revenues. We close the economy by stating the physical budget constraint and updating the Armington equations (Equation 2) to include tariff revenues *tr*.

$$y_{it} = c_{it} + in_{it} + im_{it} + \sum_{j \neq i} x_{ijt} \tag{16}$$

$$c_{it} = \left[s^{dom} (c_i^{dom} t)^{\rho^A} + \sum_{j \neq i} s_j^{for} \, (c_{ijt}^{for} + tr_{ijt})^{\rho^A} \right]^{(1/\rho^A)} \tag{17}$$

3. Solving for a Nash Equilibrium

The model features two externalities preventing that market equilibrium and social planner solution coincide: climate change damages caused by emissions, and import tariffs. In this section, we describe an algorithm that finds a Nash equilibrium for such models.

The social welfare optimization will be different from the Nash equilibrium because a social planner anticipates the external effects whereas by definition of external effects, the self-interested players of the Nash equilibrium ignore these. In case of climate change damages, a social planner would anticipate all damages (costs) associated with emissions whereas in market equilibrium damages afflicting other players are ignored. Similarly, a social planner would anticipate that tariff revenues not only get paid by the exporter but will be added to the consumption of the importing party via revenue recycling, thus raising the latter's welfare.

Our approach to compute a market equilibrium builds on Negishi (1972) and Kehoe et al. (1992). Negishi shows that a competitive equilibrium (market equilibrium) maximizes a particular social welfare function, which is a weighted sum of the utility functions of individual consumers. Hence maximization of such a social welfare function may be used to compute a market equilibrium. Kehoe et al. (1992) use optimization problems to compute equilibria for economies with externalities. They show the equivalence of their optimization problems and the equilibrium analytically.

We iterate individual welfare maximization for all players in addition to maximization of aggregate social welfare to find an equilibrium similar to the approach of Leimbach and Edenhofer (2007). We can do this without modification of the model equations by replacing variables of the optimization problems with fixed parameters and solving repeatedly in an iteration. Figure 1 shows a flow chart of the algorithm.

3.1 Phase 1: Nash equilibrium by individual maximization

We start out by finding a Nash equilibrium in everything but trade flows, i.e. strategies are made up by investment and consumption decisions. By definition, in Nash equilibrium every player selects the strategy that maximizes her welfare given the equilibrium strategies of the other players. We find a set of such equilibrium strategies by iteratively solving the welfare maximization problem of individual players, i.e. each player's strategy is determined while fixing the strategies of the other players.

In a model without trade, this is sufficient and given a decent starting point (e.g. the social planner solution) the iteration should converge quickly to the Nash equilibrium.

If trade were included, decisions about imports and exports are added to the player's strategy. In the individual welfare maximization problems this means for each player to decide on imports and exports to and from other players at given market prices. We exclude trade flows from the strategies at this stage precisely because market prices are difficult to determine.[8] Hence, in this phase we find a Nash equilibrium in investment and consumption decision for a given, fixed structure of trade flows.

We can extract price information from the model at Nash equilibrium: when trade flows are variables fixed to their levels by means of additional constraints, then the shadow prices of these constraints hold price information from the point of view of the individual players.

In general, using these prices and the fixed trade flows will not satisfy the intertemporal budget constraint (Equation 13), indicating that export and import markets are not in equilibrium. Whether there is a deficit or surplus on these markets is valuable information when we seek the market equilibrium following Negishi (1972).

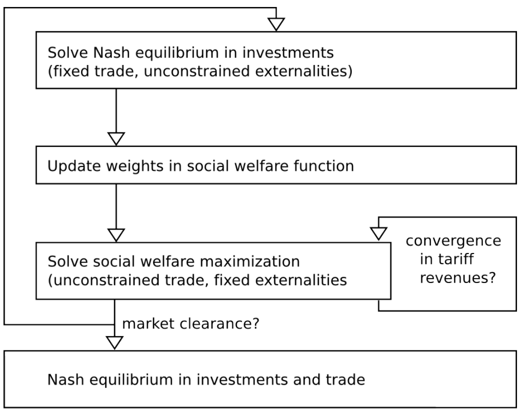

Figure 1: Flow chart of the solution algorithm.

8 In principle, market prices can be searched for by adjusting prices in response to excess demand. In an earlier, simpler version of this model, this was successfully implemented. However, in intertemporal optimization, prices at different time periods are interdependent and a robust adjustment rule for the price vectors is difficult to find. We found that convergence was slow and dependent on the choice of model parameters, and had to abandon this intuitive approach when we added detail to the model.

3.2 Phase 2: Trade flows from aggregate welfare maximization

Trade flows at market equilibrium can be derived using the approach of Negishi (1972). We maximize aggregate welfare, which is a weighted sum of players' welfare functions. Negishi's approach builds on the welfare theorems and will only find a market equilibrium for models without externalities or distortions. Thus, we fix variables that have external effects (emissions) and treat them as parameters in aggregate welfare maximization.

In the same vein we would need to fix import flows that are subjected to the tariff duty. This, of course, would defeat the purpose of running the aggregate welfare maximization to determine trade flows. Instead we separate the taxing of imports from recycling its revenue. That is, we solve the aggregate welfare maximization with imposed tariffs, but instead of recycling tariff revenues straight away we substitute tariff revenues by a parameter. Once we have solved this model, we can update the tariff revenue parameter based on the the newly calculated trade flows. We find an equilibrium solution where taxed trade flows and recycled revenues become consistent by repeatedly solving the model and updating the parameter.

3.3 Adjusting the weights in the aggregate welfare function

In order to find a market equilibrium for imports and exports, we repeat phases 1 and 2, adjusting the weights in the aggregate welfare function using the price information from phase 1. By increasing the weights of players that run an intertemporal trade surplus and decreasing weights of players running a trade deficit we find a vector of weights where all intertemporal budget constraints (Equation 13) are balanced, and hence, international markets are in equilibrium.

3.4 Testing the Nash equilibrium in investments, consumption and trade

Once the above algorithm has converged, players are in Nash equilibrium with respect to investment and consumption, and also with respect to imports and exports, and prices are market prices at which markets clear.

The Nash equilibrium property can be verified by running the following numerical test. We go back to individual welfare maximization as in phase 1, but now that we know market prices we can remove the constraints from the trade flows. Instead, we include the intertemporal budget constraint (Equation 13).

If our solution is indeed a Nash equilibrium, this test will reproduce the solution. We compare results from this test to the solution from our algorithm using the coefficient of determination R^2 as a metric.[9] R^2 values

9 This is a slight misuse of the coefficient of determination which is meant to measure how well a fitted curve explains the variation in the data. The coefficient of determination is the sum of squared errors, normalized to the interval [0,1] where 1 indicates a perfect fit, 0 indicating that the fit is just as bad as simply taking the mean. Here, errors are deviations of computed equilibrium and its numerical test, and we should hence expect R^2 values very close to 1. We use the coefficient of

are indeed very high and thus confirm the equilibrium (most R^2 are larger than 0.9999).

3.5 Partial Agreement Nash Equilibria

For the application of this algorithm to self-enforcing International Environmental Agreements (IEA), we need to extend the algorithm from plain Nash equilibrium to Partial Agreement Nash Equilibrium (PANE). Whereas in Nash equilibrium there is no cooperation, PANE defines partial cooperation as socially optimal behavior among a set of players (the coalition). PANE is a Nash equilibrium of the coalition (acting as one player) and all nonmembers. The coalition maximizes the utilitarian social welfare function, i.e. sum of equally weighted individual welfare functions.

4. Application to International Environmental Agreements

In this section we apply our model to import tariffs as a trade sanction against non-signatories of an International Environmental Agreement (IEA). Following the literature on self-enforcing IEA (e.g. Carraro and Siniscalco 1992, Barrett 1994), we consider internally stable coalitions, i.e. members of the coalition cannot improve their situation by leaving the coalition and joining the group of nonmembers free-riding on the effort of the remaining coalition.[10]

To avoid the black-box effect and to facilitate an interpretation of the qualitative effects produced by the model, we restrict the following analysis to the symmetric case of nine perfectly identical countries.

4.1 Results

Tariff's Influence on Participation

Our model confirms that tariffs can be an effective instrument to increase the scope for international cooperation: participation in the coalition is unambiguously higher when a tariff on imports from free-riding nonmember countries is applied. This result is illustrated in Figure 2: without any tariffs the largest stable coalition has only three or four members, while a tariff rate between 1.5 to 4 percent is sufficient to induce full cooperation.

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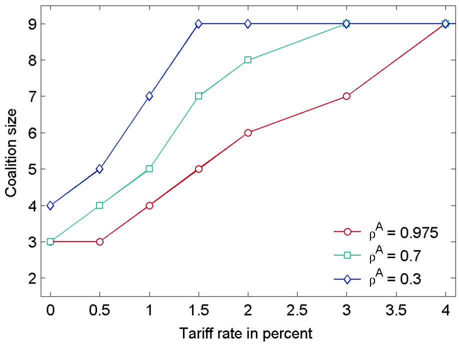
determination because it is well known and intuitive.

10 Note that we do not check *external stability*, i.e. whether the coalition is stable in the sense that no nonmember has an incentive to join. Implicitly, we assume that membership to the coalition is not open, i.e. the coalition could reject aspiring members.



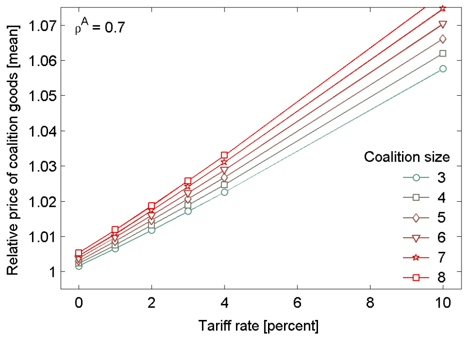


Figure 2: Participation in the coalition is raised by import tariffs. Shown are the largest stable coalitions for a given tariff.

Figure 3: Relative prices. With increasing tariffs and coalition size the price of coalition goods increases.

This effect was expected and can be understood as a consequence of our monopolistic supply assumption, in which each region produces a unique good and hence enjoys some market power. In as much as a small tariff on imports from non coalition-members leads to a rise in the relative price of goods produced by coalition members (see Figure 3), the latter obtain a benefit because they now realize a certain monopoly rent which they did not receive before. Since–by assumption–only coalition members can apply such a tariff, it constitutes an incentive to join a coalition.

As can be noted in Figure 3, not only tariffs cause the relative price of coalition goods to rise, but also the mere size of the coalition itself, even in the absence of any tariffs. The reason for this effect is that the emission reduction realized by coalition countries comes at the cost of a reduced output, hence there is–with respect to the business-as-usual–a reduced supply of coalition goods. As long as goods are differentiated, this must be reflected by a higher relative price. In fact, this possibility to pass on mitigation costs to free-riders also explains why larger coalitions became stable even without tariffs if only the elasticity of substitution between goods is lowered, as seen on the y-axis of Figure 2.

The graph in Figure 2 also shows how the effectiveness of tariffs becomes lower for higher elasticities of substitution. For example, a tariff of 1 percent leads to a stable coalition with 7 out of 9 member countries if $\sigma = 1.43$, 5 members for $\sigma = 3.33$ and 4 members for $\sigma = 40$. In view of the fact that a higher elasticity implies higher substitutability and hence lower market power, this behavior is fully consistent with our explanation.

Environmental Effectiveness of Co-operation

A common argument brought forward against climate coalitions with incomplete membership is the leakage problem: the effectiveness of any collective effort by the coalition could be undermined, if not annihilated, by free-riders who increase their emissions as a response to the coalition's reductions. As Figure 4 illustrates, the extreme case of 100 percent leakage rate is not present in our model. Instead, we observe even for the relatively high elasticity of $\sigma = 40$ that an increase in the coalition size always leads to a reduction in cumulative global emissions. However, as the neighboring Figure 5 shows, free-riding countries do cause some leakage, albeit to a limited extent, that would not warrant to discourage cooperation between a subset of countries.

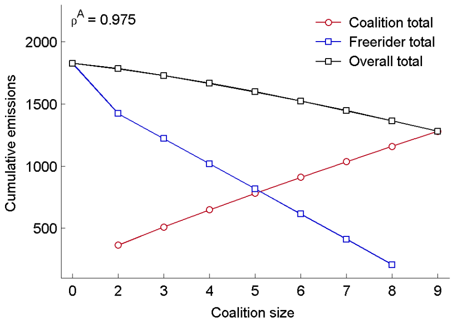


Figure 4: Effect of coalition formation on total cumulative emissions.

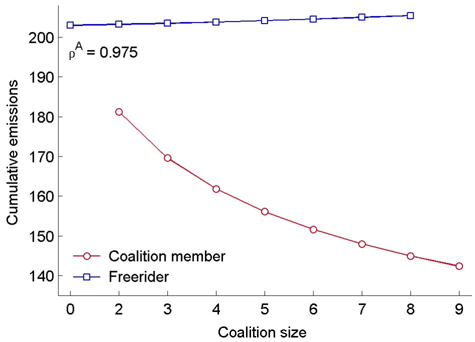


Figure 5: Average free-rider and coalition member emissions as function of coalition size.

Credibility of Tariffs

Threatening to impose tariffs is only credible if the coalition is actually better off with than without tariffs.[11] Within our model, tariffs provide a means for coalition countries to exploit their market power as suppliers of a unique good. Similar to a price setting monopolist, this should be beneficial as long as tariffs are not set too high, the limit depending on the elasticity of substitution. This intuition is confirmed by Figure 6, which shows how a coalition's welfare changes with increasing tariffs.

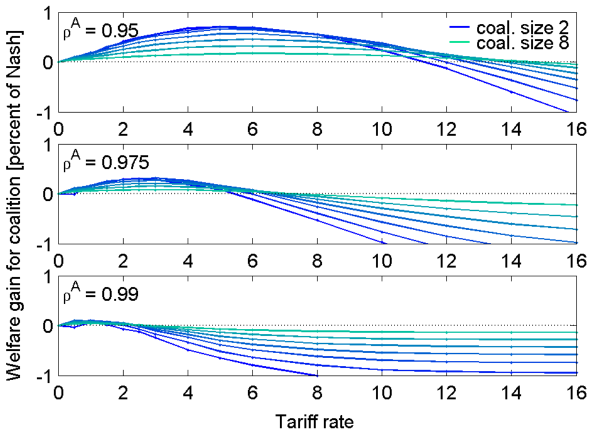


Figure 6: Credibility of imposing tariffs. Negative welfare gains indicate tariff rates that are not credible.

As expected, welfare also increases, but then, after reaching a maximum value, it starts to decline and eventually becomes negative. The threshold

11 The hereby implied concept of credibility is rather shortsighted: by considering only the welfare effects of tariffs on themselves, coalition members ignore that the coalition-stabilizing effect of a tariff might bring about net positive welfare effects even with 'incredible' (according to our concept) tariffs. This, however, is in line with our employed concept of stability.

value at which the welfare effect turns negative marks the maximum tariff rate that is still credible.

Although the observed qualitative pattern is robust with respect to parameter changes, the specific value of the maximum tariff as well as the potential welfare gain depend on the elasticity of substitution ($\sigma = 1/(1-\rho^A)$) as well as on the coalition size: both become higher for low elasticities and smaller coalition sizes. For example, for $\rho^A = 0.95$ (implying $\sigma = 20$) tariffs of more than 10 percent are always credible, while for $\rho^A = 0.99$ (implying $\sigma = 100$) the cut-off is at around 2 percent. This dependence on ρ^A can easily be explained in terms of the greater market power implied by a low elasticity, which results in a larger scope for tariffs. The observable higher welfare gain for smaller coalitions is a consequence of higher tariff revenues: in the presence of large coalitions there are only few free-riders left whose goods are actually subject to tariff duties, while there are payments from almost all trading partners if the coalition has only two members.

Welfare Implications of Tariffs

Tariffs have an ambiguous effect on global welfare: on one hand they should increase welfare because they enhance the scope for cooperation. On the other hand–as free trade advocates might object–they distort free trade and thus undermine global efficiency, which should lead to a loss of welfare and could in the worst case annihilate all gains. We compare the two opposing effects in Figures 7 and 8.

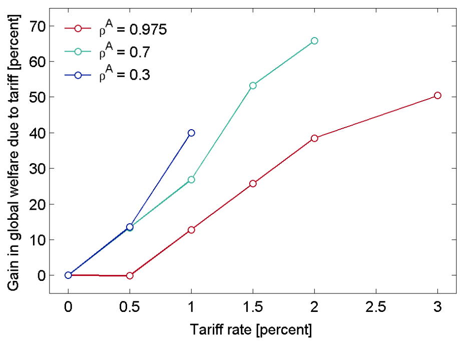


Figure 7: Gains in global welfare due to tariffs. Relative to a world without tariffs, cooperation is enhanced and global welfare increases.

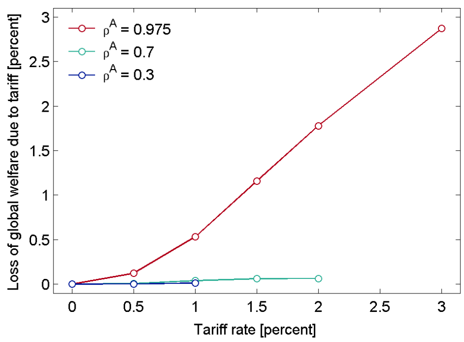


Figure 8: Losses in global welfare due to tariffs. For any coalition equilibrium, global welfare would be higher without the distortionary effect of tariffs on trade.

Figure 7 shows gains from tariffs measured as the difference in global welfare between the largest stable coalition with a given tariff rate and the largest stable coalition in the absence of tariffs.[12] [The last point of every curve represents the grand coalition, the stability of which–as seen earlier–requires higher tariff rates if goods are more substitutable.] Clearly, the cooperation enhancing effect of tariffs also brings about significant global welfare gains.

12 Normalized (in both figures) to the scale defined by the welfare gap between the Nash equilibrium and Pareto optimum.

In contrast, the welfare losses caused by the distortionary effects of tariffs are shown in Figure 8. They are measured by taking the largest stable coalition at each tariff rate and computing the increase in global welfare achieved by switching the tariff off (ignoring that the coalition may not be stable anymore). The graph confirms standard economic theory in as much as it shows how welfare losses increase steadily as a function of increasing tariff rates. However, the welfare losses due to the trade distortion are one order of magnitude smaller than the gains achieved because of the enhanced cooperation. In normative terms, this suggests that the trade distorting effect of tariffs should be an acceptable price to pay in order to help bringing about more inclusive climate coalitions.

5. Conclusions

This study aims to make a methodological contribution to integrated assessment modeling. We propose a model in the tradition of multi-regional optimal growth models that includes trade relationships between regions. Including climate damages and punitive tariffs introduces two external effects into the model. Thus the market equilibrium will fail to be socially optimal and a more elaborate approach than social welfare maximization is necessary to find an equilibrium solution.

We address this challenge by presenting an algorithmic extension to the approaches by Negishi (1972) and Kehoe et al. (1992) that allows us to solve for an equilibrium without modification of the model equations.

We demonstrate model and algorithm by applying the model to the timely question of trade sanctions as an instrument to foster participation in an International Environmental Agreement. We find:

- When the coalition imposes tariffs on imports from free-riding regions, participation in the coalition rises. Global social welfare rises along with participation despite small welfare losses due to the distortion caused by the tariff instrument.
- To threaten non-members with trade sanctions is credible as long as the tariff rate is small. For large tariff rates coalition members would be better off not to sanction trade.
- Non-members respond to emission on the part of the coalition by raising their own emissions, but we find this leakage effect to be small.

These results are comprehensible in light of the strong assumptions about the market structure: completely specialized regions produce goods that are imperfect substitutes among each other. Yet they act as price takers in a competitive equilibrium. Introducing tariffs in this context allows coalition members to realize part of their potential monopoly rents. The elasticity of substitution between goods determines the ease with which non-member can avoid coalition goods, and hence puts a limit on the potential clout of the tariff instrument.

The application of the model nevertheless identifies some robust qualitative relationships and clearly demonstrates the usefulness of the algorithm. Within this framework, future research can relax some of the strong modeling assumptions. For example, by replacing price taking behavior with optimal price setting, the scope of the tariff instrument within a more realistic representation of the economy can be explored. Naturally, the assumption of symmetric regions makes this a stylized study. Introducing heterogeneity and calibrating players to real world regions would further increase the policy relevance of the model results. Moreover, the treatment of externalities sketched in this paper should be transferable to similar dynamic games with externalities.

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6. Appendix: Parameter Choices

Table 1 lists our choice of parameters. We restrict this study to the case of symmetric players, hence a calibration to real world regions is out of question. Nevertheless we selected a set of parameters such as to produce a scenario that is not surreal. This appendix lists the assumptions we made.

We chose the rate of exogenous labor enhancing technological change such that economic output shows a 2.6 percent annual growth.

With initial labor and labor productivity at 1.0, we chose initial capital such that the savings rate is constant at 23 percent over the course of the first century.

We frequently vary the Armington parameter ρ^A that determines the elasticity of substitution in our experiments. To enhance the comparability of calculations with different ρ^A we selected the share parameters s^{dom} and s^{for} such that for all ρ^A the export ratio is about 30 percent in the Nash equilibrium.

Parameters in the climate module are based on literature values, giving us a 3°C temperature increase by 2100, and a 7.5°C increase by 2200 in Nash equilibrium and business as usual, i.e. without climate change damages.

The damage function was chosen such that in Nash equilibrium damages in 2100 are 6 percent and 17 percent in 2200.

Within the mitigation option, parameters ψ and *iekm* were selected such that optimal abatement (the social planner solution) reduces the temperature increase in 2100 to 2.4°C.

Parameter	Symbol	Value
Pure rate of time preference	ρ	*0.01*
Income share capital	β	*0.35*
Labor productivity growth	gr	*0.023*
Autonomous emission intensity	ei_t	*exp(-0.01 t)*
Initial labor	l_0	*1*
Initial labor productivity	a_0	*1*
Initial capital stock	k_0	*34*
Share parameter, domestic	s^{dom}	*see text*
Share parameter, foreign	s^{for}	*see text*
Armington elasticity of substitution	ρ^A	*0.975*
Effectiveness of investments in *km*	$iekm$	*5.0*
Abatement cost exponent	ψ	*0.2*
Parameter β in Petschel-Held et al.	β^P	*0.47*
Parameter B in Petschel-Held et al.	B	*1.51e-3*
Parameter μ in Petschel-Held et al.	μ	*8.7e-2*
Parameter α in Petschel-Held et al.	α^P	*1.7e-2*
Parameter σ in Petschel-Held et al.	σ^P	*2.15e-2*
Initial concentration	$conc_0$	*377*
Initial temperature	$temp_0$	*0.41*
Initial cumulative emissions	$cume_0$	*501*
Damage function coefficient	$dam1$	*0.02*
Damage function exponent	$dam2$	*1.5*

Table 1: Parameter values.