Sustainability in the Political Economy

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Abstract

Abstract to be written here.

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1. Introduction

There have been many international environmental agreements (IEAs) entered into between countries to reduce environmental degradation which have fallen short of their objectives. For the non-renewable resources within the economy to be allocated efficiently in a way that considers sustainability for future generations requires co-operation among countries (Buchholz *et al.*, 2005). In practice, true co-operation that is ensured by credible commitment to policy preferences is difficult to achieve. In fact, international agreements between countries may be counterproductive if citizens do not fully internalise the joint impact of consumption on the probability of a climate crisis.

In this thesis, the framework from Buchholz *et al.* (2005) is employed and extended for studying the issue of international co-operation regarding environmental policies. Their framework assumes symmetry between two countries and that there is a trade-off between environmental policies and gross domestic product. The paper thus suggests countries pay each other side payments to compensate for transboundary pollution emitted from their own country to another. Their main result is analytically determining the global population result, the non-cooperative result, and the bargaing outcome which lies between the first two results.

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This thesis extends the framework from Buchholz *et al.* (2005) in two novel ways. The first contribution is to create a simplified framework to model sustainability in a formal way that enables the incorporation of a non-linear trajectory of resource consumption over time. If a climate crisis occurs, then the path of consumption is permanently shifted with severely reduced consumption options for the next period. The second contribution of this thesis is to use a numerical modelling approach. This approach enables the study of more nuanced questions and specifically, in this case the inclusion of asymmetries between countries which could otherwise not be accomplished in a purely analytical model approach.

Albeit that to replicate the full analysis that Buchholz *et al.* (2005) conducts with this new framework is beyond the scope of this thesis, the following results are found. The outcomes under perfect cooperation in the global democracy are determined, and the outcomes under a fully non-cooperative interaction between a partitioned global democracy into two countries, where each country has an elected candidate voted in according to the voting decisions of the citizens who take the other country's consumption decisions as given.

This yields the threat points for bargaining equilibria which is left for future research. I show that similar results arise as in Buchholz: When two countries elect representatives strategically, the level of consumption chosen and hence the probability of a crisis is far higher that what would be chosen in the cooperative environment. This implies that any Nash bargaining solution will also be suboptimal, although that is beyond the scope of this paper.

Next i show how these threatpoints and final probability of crisis depends on asymmetries in country size and opinions. (summarize the main result explicitly here)"

Some papers suggest that IEAs are ineffective because of strategic voting by voters to ensure their own country's bargaining position is stronger (Buchholz *et al.*, 2005). The primary objective of this research assignment is to model how interactions in the political economy inhibit IEAs. Ultimately, we wish to understand how the dominance of certain countries in the global context impacts IEAs. For example, a country which is geographically larger than another and thus has more voters may lead to sub-optimal outcomes in comparison to a model considering only one large global population. Similarly, if one country's citizens hold more optimistic beliefs about the worst case scenario which may arise if environmental degradation passes some threshold then this too may lead to sub-optimal outcomes.

Our paper suggests that the mechanism behind these sub-optimal outcomes in a two-country IEA is strategic voting if voters take into account the impact of another country's consumption level into their own best response function. This is because our model assumes each voter receives a random private signal that determines their beliefs about the worst case scenario if environmental degradation crossed some threshold. These beliefs are then mapped onto probability of crisis beliefs.

EXPLAIN STRATEGIC…BELIEFS THE SAME BUT OUTCOMES DIFFERENT Thus, strategic voting may diminish the effectiveness of IEAs. This is made evident by the finding that when two countries are of a similar size, the Nash equilibrium outcome yields a much higher consumption level and probability of crisis than when one country is much larger than the other.

If perfect co-operation cannot be ensured, then it may be better to allow countries to unilaterally set their own environmental policies, as this may yield greener winning political candidates, reduce pollution, and provide a higher payoff for the median voter (Buchholz *et al.*, 2005). Buchholz *et al.* (2005) investigates the sub-question of how to bind a country to implement their true policy preferences in an agreement, and this is still inconclusive.

The model we set up first considers the simplest case of a two-period optimisation problem. There is a world with abundant resources, where consumers believe that they can consume a lot today and tomorrow, and information about the state of the world is aggregated perfectly. As we continue to model this problem, frictions are added. For example, the state of the world may not be aggregated correctly to the voters. For our model, the focus is how the political system works when there is the issue of environmental degradation. Accordingly, the literature on both sides of the sustainability of the political economy is considered. Namely, the literature on exhaustible resources (including the optimal depletion thereof and the cake-eating optimisation problem) and the political economy (including the aggregation of political information and strategic voting).

The first specification of the state of the world will be modeled within a global economy in which there is only one population of voters and information is aggregated imperfectly. The second specification of the model will introduce the two-country setting and how adjustments to the bias of voter signals and the relative size of the countries may affect each country's citizens' voting decisions. Thereafter, the two specifications will be compared to each other to determine how co-operation between countries with regards to environmental policies may be disadvantageous for consumption and may make the probability of a crisis more likely.

2. Literature review

(2400)

The literature review for this thesis will be organised as follows. First, the literature pertaining to the extraction of non-renewable resources in a single economy setting is discussed. Secondly, within the same context, the information aggregation literature is discussed. Finally, the consideration of co-ordination across countries relating to these issues is then discussed.

The literature which models the utilisation and extraction of non-renewable resources began with contributions that did not incorporate uncertainties (Pindyck, 1978). Thereafter, it developed to consider the impact of consumption in the present period on the resources remaining for the following period (Adler & Treich, 2017), and ultimately began to incorporate the possibility of consumption in the present period as a determinant of the probability of crisis (Loury, 1978; Kumar, 2005; Lemoine & Traeger, 2014).

Pindyck (1978) models two different optimal paths for using non-renewable resources which depends on the initial resource endowment and the different marginal costs of extraction for different resources. If the initial reserve endowment is large, then this causes extraction costs to be low and thereby the price will slowly rise over time as the resource depletes. On the other hand, if the initial reserve has already been depleted and there is only a small quantity remaining, both the price and the extraction costs will be high. As reserves decline, the production cost for using resources increases and potential profits reduces. Accordingly, as marginal costs increase for extraction, producers will begin to conserve non-renewable resources because the marginal benefit thereof is smaller.

Pindyck (1978) can be incorporated into a model of sustainable consumption by modelling that there is a cost in the future if consumption in the present period is too high. Consumption of resources is thus only sustainable if consumption in the present period does not impose a cost in the next period. However, the model in this paper does not consider the more realistic situation in which the non-renewable resource quantities are uncertain and thus does not address the possibility of exhausting a resource in its entirety.

Adler & Treich (2017) consider three dimensions of climate policy to be modelled: (i) equity, (ii) time, and (iii) risk which each impact how risky consumption is allocated intertemporally. These three dimensions can be interpreted as beliefs which are used in our model to inform the optimal level of consumption and probability of crisis. The cake-eating problem for an uncertain quantity of resources with a social planner who allocates between the current and future generation is modelled in terms of three different social welfare functions. The first generation is given a determinate amount of consumption, but the second generation is given the risky remainder. Our model also includes only the first period's consumption as the choice variable which then impacts the second period, but instead of first period consumption directly impacting what is remaining for the next period, in our model consumption impacts the probability of crisis. The methodology used is a prioritarian social welfare function (SWF) which is the sum of some increasing, concave function of utility for the well-being of a generation. To find the optimal consumption allocation, Adler & Treich (2017) compare statics analysis for the different functions.

These aforemetioned papers, however, do not consider the uncertain thresholds which cannot be exceeded without incurring a cost, more specifically without altering the trajectory of an economy permanently, such as enterring a crisis. Kemp (1976) was the first to consider the cake-eating optimisation problem for a non-renewable resource of an unknown size and has since been developed in the literature. Loury (1978) investigates the optimal planning for an economy faced with two main problems; (i) the possibility of exhaustion of the resource, and (ii) learning about the distribution of reserves over time through exploration and extraction activities.

Under certainty, when the size of the resource reserve is known, Loury (1978) finds that the possibility of exhaustion occurs only asymptotically. However, when the resource reserve quantity is of an unknown size, the date upon which it will have been completely exploited is also a random variable. The choice of the rate of consumption is necessarily affected by the impact of the consumption rate on the probability of crisis, or likelihood of reaching the tipping point. This feature is incorporated directly into our model as the consumption in period one which is believed to be optimal directly determines individual's beliefs regarding the optimal probability of crisis, and thus affects the choice of consumption.

Loury (1978) demonstrates that the possibility of premature exhaustion alters the requirements of an optimal consumption path. The model used in this paper specifies some minimal level of resource consumption that is necessary to sustain an economy, which is incorporated into our model as the lower consumption threshold. Moreover, the uncertain reserve of resources is modelled in Loury (1978) as a random variable that is drawn from a cumulative density function, which is a mechanism that our model similarly employs to draw unknown values.

Kumar (2005) reconsiders Kemp's use of an infinite planning horizon by instead using a hazard function which is defined as the probability of reaching the climate tipping point. The paper argues that 'cake-eating under uncertainty' has two main aspects: (i) the optimal planning horizon and (ii) the characterisation of the optimal program. The former aspect of the (i) optimal planning horizon can be assumed to extend far enough into the future to allow for the resource to be fully exhausted at some point. By employing a hazard function to model the problem, the planning horizon over which consumption of the exhaustible resource is positive has been found to be either finite or infinite.

The main findings of Kumar (2005) are that if an uncertain resource stock is finite and the optimal planning horizon is finite, hazard rates increase in unbounded fashion, and marginal utility of extraction and consumption at zero is finite. However, if an uncertain resource stock size is unbounded, the planning horizon is infinite. Thus, the optimal rate of extraction and consumption over time generally moves monotonically in the opposite direction to the hazard rate.

Lemoine & Traeger (2014) addresses the need to integrate policy with possibility of climate tipping points into a benchmark integrated assessment model to analyse the intertemporal trade-offs which characterise climate policy decisions. Crossing the threshold shifts the world permanently to a new altered system with different dynamics to the state of the world pre-threshold. The paper demonstrates with an analytical model that optimal policy is impacted by tipping points via two channels; namely (the differential welfare impact (DWI) recognizes that the present period's policy choices affect (i) welfare if a tipping point occurs, and (ii) the probability of crossing the threshold. Accordingly, the paper's model endogenises welfare and the probability of a tipping point occuring, which our model incorporates.

On the political economy side of the literature, Piketty (1999) provides a short summary of recent contributions to the literature related to political institutions as an information-aggregation mechanism since the first contribution by Condorcet. Other papers modelled voting behaviour according to an individual's best response function dependent on their own voting type and preferences (Lohmann, 1994) or dependent instead on the voting behvaiour of others (Besley & Coate, 1997; Buchholz, 2005). On the other hand, Razin (2003) modelled that voters may adjust their voting behaviour to influence either the likelihood of their candidate getting into office or their preferred policy being implemented. Many models of political economy include different stages to analyse how voting impacts policies but vary according to how voters' derive utility (Lohmann, 1994; Besley & Coate, 1997; Razin, 2003; Buchholz *et al.*, 2005). Our model does not include voting stages explicitly, but instead models two stages of resource consumption, and draws different aspects from the following papers.

Condorcet was the first to posit that political institutions have a constructive role in efficiently aggregating information in a society. His main contribution to the literature was termed the 'Condorcet Jury Theorem' which states that under free elections, the probability that the policy that is preferred by the majority will win by majority vote tends to one as the number of individuals in the population tends to infinity. This theorem posits that democracy is an efficient information-aggregation system if it is assumed that individuals are homogenous in both their initial prior beliefs about the state of the world and their utility functions.

Condorcet also assumed voters vote sincerly in accordance with their beliefs and do not engage in strategic voting. Piketty (1999) finds that towards the end of the twentieth century, formal political models began including information economics, and may indicate a return to the approach of Condorcet. Extensions of the Condorcet model incorporated the more realistic nature of information in an economy; information is never fully integrated, but rather exists in an economy as dispersed, incomplete and often contradictory pieces. Thus, it has since been modelled that each individual receives a signal drawn from the same conditional distribution, which has been used in developing our model.

Lohmann (1994) investigated the impact of the information aggregated by political action on whether votes are more or less accurate, where accuracy is defined in terms of reflecting voters' preferences. The paper models that each individual has a loss function which accounts for the loss if the policy outcome is not what the individual desired and the private cost if the individual engaged in political action.

The equilibrium point is where an individual's political action strategy minimises their expected loss after the political action stage. To analyse voter behaviour, Lohmann (1994) uses game theoretical best responses at each voting stage. For example, at the political action stage, a voter's best response is a function of the 'type' of voter that they are and the individual preferences which they have. Similarly, our model uses best response functions for voting behaviour but omits the consideration of voter types, as voters are distinguished only by their private signals.

Razin (2003) models elections with only two potential candidates in a one-dimensional policy space. Voting behaviour is strategic as voters are motivated by both the election and signalling implications of voting. Election motivations refer to voters deciding to vote to influence which candidate wins the vote, whereas signalling motivation refers to voters voting to influence which policy the winning candidate will implement. In our model, it is assumed instead that the winning candidate will credibly commit to implementing their own preferred policy and voters may engage in strategic voting to bolster their own country's bargaining position in the two-country model. Razin (2003) assumes that voters are privately and imperfectly informed about a common shock which impacts voters' preferences. Voters' private signals are drawn independently from a distribution and are conditional on the common shock. Our model adopts the same mechanism to determine voters' beliefs, albeit without the inclusion of a common shock to the economy.

Buchholz *et al.* (2005) investigates the policy outcome which may arise from IEAs when governments are democratically elected by citizens. This paper considers two pertinent themes, namely the case in which a voter may be incentivised to support a political candidate who is less environmentally inclined than the voter's own preferences, and the case in which the elected candidate pays no attention to environmental policies, and thus international agreements are rendered as ineffective. The paper argues that an efficient allocation of resources that is sustainable requires co-operation between countries, but that there is a far way to go before IEAs are fully enforced to function fully cooperatively as they are intended.

According to Buchholz *et al.* (2005), one possible reason for ineffective IEAs is that voters are incentivised to deliberately support candidates with different environmental preferences to their own in order to improve their country's bargaining position in international negotiations. Our paper investigates a very similar research question and adopts a similar methodology. The methodology of

Buchholz *et al.* (2005) is to use the median-voter approach with Nash bargaining in a simple two-country model and then compare the isolationist case (in which there is no IEA between countries) to the cooperative case (in which there is an IEA).

The paper compares the two different cases and finds that countries will be incentivised to improve their bargaining position in an IEA by introducing less green policies, than they would otherwise in a unilateral arrangement. The paper models the electoral system in a stylised way which means that the winning candidate is determined when they win every pairwise comparison with all other candidates and assumed that the competing candidates have different types ranging between 0 and 1. Our model also uses the pairwise comparison for each voter to determine which candidate would yield their highest expected utility. However, Buchholz *et al.* (2005) provides attention to varying degrees of transboundary pollution, which refers to one country's polluting impact on another country, whereas our paper focuses more on the impact of varying the size of countries and introducing biased beliefs to assess how this may impact the voting in a two-country model.

On the other hand, Besley & Coate (1997) sets up a model of representative democracy in which citizens have the choice to avail themselves as candidates to run for public office. The model assumes that candidates must credibly commit to implementing their preferred policy if they win the election and voters then vote accordingly. Voters derive utility from the ultimate policy outcome and the winning candidate's identity. Voters derive disutility from the cost of running for office if they decide to do so. There is strategic voting because voters' voting decisions are optimal if they are a best response, given the rest of voters' decisions. The paper defines the equilibrium policy choice as efficient according to a Pareto optimal definition; meaning that there are no alternative policy choices in the present period that could increase the expected utility of all citizens conditional on future policies that are democratic in nature.

However, this model assumes complete information. It recommends that future research incorporates uncertainty regarding voters' preferences and endogenises the formation of parties or candidates that run for office. Unlike Besley & Coate (1997) which accounts for the policy outcome and winning candidate's identity as providing utility and the cost of running for office as providing disutility, our model simplifies away the cost of running for office to simply understand how international co-operation may move countries away from better environmental policy outcomes than if they acted unilaterally.

To conclude, this thesis models both sides of the literature discussed in this section in a simplified way??. The interaction between two countries which vote for how non-renewable resources should optimally be extracted to avoid a tipping point is incorporated with the information aggregation in the political economy. Thus, the political economy model with consumption decisions can be extended to analyse co-ordination between two countries in this regard.

3. A model of sustainable consumption in a global democracy

(1250)

The first specification of the model serves as a benchmark of the most efficient information-aggregation system that may arise from majority voting in a global democracy. There is only one population of voters. Information is aggregated imperfectly and voters are uncertain about the true penalty that the economy will face if consumption today exceeds some threshold. The model is simulated in Matlab and the built-in optimisers in the programme are used to find the optimal points. First, the economy will be specified in a context with an unknown penalty if a crisis occurs and then the probability of crisis will be incorporated. Thereafter, the consumer problem and voting process will be presented.

Economy

In order to model sustainability in the political economy, we first set up a simple model of sustainable consumption over two periods $t = 1, 2$. The choice variable in this economy is consumption in period one (c_1). Consumption in period two (c_2) is stochastic and dependent on the value of c_1 as follows. c_1 is defined as sustainable if it is below an unknown threshold value ($\tilde{c}$). This is because if c_1 is sustainable, then c_2 can also be set at the same level ($c_1 = c_2$). However, if c_1 is unsustainable, and exceeds $\tilde{c}$ in period one, then the economy will face a climate crisis, and consumption is dramatically reduced to some very low level ($\underline{c}$). As a result, c_2 will be much lower than c_1 ($c_1 > \underline{c}$). Thus, we can model c_2 as a function of c_1 as follows:

$$c_2\left(c_1\right) = \begin{cases} c_1 & \text{if } c_1 \leq \tilde{c} \\ \underline{c} & \text{otherwise} \end{cases}$$

Consumers

The decision problem faced by consumers in the global democracy is to maximise their lifetime utility as follows:

$$U(c_1) = u(c_1) + \mathbb{E}u(c_2(c_1))$$

$$\text{subject to } c_L \leq c_1 \leq c_H$$

We assume that the unknown tipping point $\tilde{c}$ is uniformly distributed btween two known boundaries c_L and c_H. In this setting, c_L represents the safest level of consumption at which the probability of a crisis is zero. This can be regarded as some minimal level of consumption that is necessary to sustain an economy or the very least amount of resources that are required to continue living (Loury, 1978). On the other hand, c_H represents the maximum consumption value that may be consumed in period one at which the probability of crisis is one. This can be regarded as some upper bound of consumption possibilities where it is certain that the threshold $\tilde{c}$ will be reached. Due to the uncertain value of $\tilde{c}$ that is drawn from a uniform distribution between c_L and c_H, c_H thus represents a certainty of reaching the "tipping point" (Kumar, 2005; Lemoine & Traeger, 2014). Accordingly, if this unknown threshold $\tilde{c}$ is exceeded, the crisis occurs below c_H.

$$\Pr(\tilde{c} \leq c_1) = \begin{cases} 0 & \text{if } c_1 \leq c_L \\ \frac{c_1 - c_L}{c_H - c_L} & \text{if } c_1 \in (c_L, c_H] \\ 1 & \text{otherwise} \end{cases}$$

We make the assumption that the utility functions of all consumers are homogenous (Piketty, 1999) where the utility derived from consumption is assumed to take the relative risk aversion functional form and ρ is assumed to be set at 1.5 as follows:

$$U(C) = \frac{c^{1-\rho} - 1}{1 - \rho}$$

To introduce a role for political aggregation of private information in the model, we assume that there are different beliefs about the severity of the climate crisis if the tipping point is crossed. Specifically, as in Besley & Coate (1997), we assume that individuals differ regarding their beliefs about the level of consumption that would be possible if the crisis occurs ($\underline{c}$). These beliefs are determined by private signals $\hat{\underline{c}}_k$ which consumers receive. These signals are noisy and conceal the true value of $\underline{c}$ as follows:

$$\hat{\underline{c}}_k = \underline{c} + \varepsilon_k$$

$$\text{where } \mathbb{E}\left(\varepsilon_k\right) = 0$$

We assume that these private signals $\hat{\underline{c}}_k$ are drawn from a distribution between c_L and c_H. This is a realistic assumption because in the real world consumers are exposed to a variety of news sources and political action which each suggest different probabilities for future climate outcomes (Piketty, 1999; Lohmann, 1994). Thus, information aggregation is not perfect in this model.

From the signals that are drawn randomly for each individual, there are different associated optimal probability of crisis points. The different signals that individuals draw determine their beliefs about which probability of crisis is optimal, and thus lifetime utility constitutes the utility derived from consumption in period one c_1 and the expected utility of the weighted probability average of period two consumption as follows:

$$U\left(c_1 \mid \hat{\underline{c}}_k\right) = u\left(c_1\right) + \Pr\left(\tilde{c} \leq c_1\right) u\left(\hat{\underline{c}}_k\right) + \left(1 - \Pr\left(\tilde{c} \leq c_1\right)\right) u\left(c_1\right)$$

In this model, the thresholds of consumption in period one are set as exogenous, fixed parameters. The global population is set to 1000. The set of possible consumption choices are set to 100 and are bounded between the thresholds, which are set to $c_L = 0.5$ and $c_H = 1.5$ respectively. These choices are arbitrary, but serves as a proof-of-concept of this numerical model structure. Future research will extend the specifications to be more realistic or calibrated to scientific and economic data. However, adjustable parameters are introduced into the two-country model in the subsequent section of this paper.

Figure 3.1 shows the cumulative distribution function of the probability of crisis. It is curved due to the relative risk aversion functional form. Figure 1 indicates that individuals who receive higher private signals believe that the consumption level that is possible if the climate crisis occurs will be higher, and thus will optimally prefer a higher probability of the crisis occurring. An individual's optimal probability of crisis depends on the signal provided to the individual. The higher the signal, the higher the optimal consumption point and thus the higher the optimal probability of crisis.

On the other hand, individuals that have been provided with information which indicates that the climate crisis will be mild will consume more and thus be comfortable with a higher probability of crisis. Thus, beliefs are a key driver of consumption choices in our model. This model builds on Besley & Coate (1997)'s model which selects candidates exogenously and assumes complete information within the economy. Our model instead assumes imperfect information and unique signals that are randomly provided to each voter.

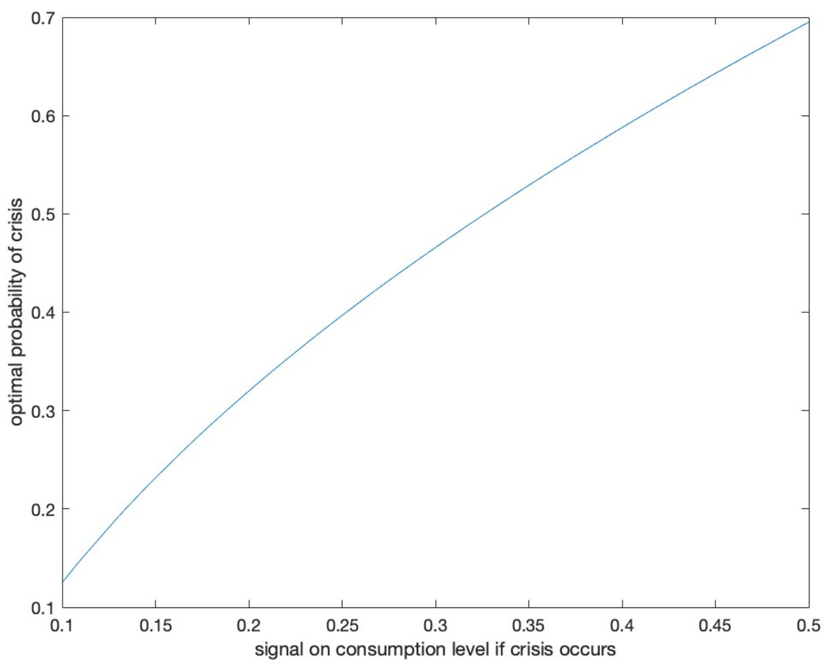

Figure 3.1: Optimal probability of crisis as mapped from different beliefs about the optimal consumption level

Voters

Voters are assumed to be homogenous in all respects except their beliefs; which are determined entirely by the private signals that they receive. Besley & Coate (1997) find that according to the median voter result and the Condorcet Jury theorem, there is one ultimate winning candidate which is the median voter. According to the median voter theorem, if preferences are single peaked (which is implied by the uniformly distributed private signals in this model which determine beliefs) then the median voter will be the winning candidate in a global democracy vote, if we assume voter sincerity and a democratic voting system.[1]

It is further assumed that voting is conducted according to simple majority voting and that each candidate could be running for public office. As such, voters are assumed to have a continuous choice set of possible candidates which ranges across the different beliefs of individuals in the economy exactly. Voting is thus endogenised, as the winning candidate is the candidate that yields the highest expected utility for every pairwise comparison (Buchholz *et al.*, 2005)

To determine the winning candidate, each voter considers each pairwise comparison between each individual's policy preferences. Voters are assumed to know that candidates could only implement their preferred policy. This is a realistic assumption as it follows from the assumption that that candidates cannot credibly commit to any other policy other than their own policy preference and voters know this. Policy preferences are thus in this context their individual optimal consumption point and how this maps onto their optimal probability of crisis. Based on the pairwise comparison, the voter votes for the individual which maximises their expected utility.

4. Consumption choices in two non-cooperative democracies

(approx 731)

The primary concern in this thesis is to model the failure to co-ordinate environmental agreements between two countries. This is modelled in a similar way as Buchholz *et al.* (2005), but only gives consideration to the non-cooperative result. We assume that there are two countries which are a partition of the global democracy population and function independently of one another. The key mechanism is that each country independently determines their own consumption value (as chosen by the winning candidate for each country upon which was voted independently), but the probability of

[1] The median voter result was checked numerically and holds up to numerical precision.

a global climate crisis is determined by the average consumption level across the two countries. There is a discrepancy between voting conducted unilaterally and ultimately facing the joint consequence globally. Thus, consumers in a given country do not fully internalize the costs and risks of their consumption choices in the two-country setting.

Economy

To develop the model set-up further, the impact of another country's consumption level on the optimal level of consumption is incorporated. Accordingly, this model specification introduces two countries; country A and country B. The implications of a two-country model which considers the interdependence between countries is more realistic. A prime example is the consideration of the impact of an IEA, as considered in Buchholz *et al.* (2005).

Consumers

As in the global democracy model, individuals in each country receive private signals $\hat{\underline{c}}_k$ which determine their optimal level of consumption. These private signals are drawn again from a distribution between c_L and c_H, and are identically distributed in each country unless adjustable parameters are altered to create asymmetries. Individuals in the global economy are split into two different country populations according to a stochastic assignment, after each individual has received their private signals. Each individual is divided probabilistically into either country A or country B to ensure random splitting.

We study two dimensions of asymmetries in this model specification, namely in the relative size and bias in the beliefs of the countries. Variations in relative country size can be implemented by selecting a value between 0 and 0.5. The higher the relative country size value, the larger country A's population size is relative to country B. Variations in belief bias can be implemented by selecting a value between 0 and 0.9. The higher the belief bias value, the more likely that those individuals who receive higher private signals are to be assigned to country A, and thus the more optimistic on average the beliefs are in country A.

Voters

As in the global democracy, the expected utilities for every possible candidate are computed under the assumption that each citizen runs for election and promises to implement their own ideal consumption level if elected. Accordingly, each voter considers any pairwise competition based on their expected utility and their own belief about $\tilde{c}$ as formed due to their private signal $\hat{\underline{c}}_k$.

Thereafter, the mutual best responses for each country given what the other country's consumption level is are determined. Each country's citizens vote for the candidate in their respective country that will yield the best response given how the other country votes to maximise expected utility. For example, if country A is biased to consume at a high level, then it would be a best response for country B to consume at a lower level to reduce the probability of crisis to be closer to country B's optimal probability of crisis. The Nash equilibrium in the two-country model is determined using Matlab's built-in optimisers.

In each country, each individual has a best response function and votes for the candidate that maximises their expected utility, conditional on the other country's consumption level as well as their own consumption level. However, albeit that the other country's consumption level is taken as given, individuals do not fully internalise the joint impact of both countries' average consumption on the probability of crisis.

In the case of strategic considerations that are not fully internalised, there are two main findings. Non-cooperative results between two parties are found to be worse than cooperative results, and Nash bargaining results are found to lie somewhere in between these two polarised results. Thus the focus of this paper is to analyze how the non-cooperative results depend on asymmetries which Buchholz *et al.* (2005) do not study, and leave the bargaining results which their paper investigates for future research.

5. Results and discussion

(1130)

To analyse whether a lack of co-operation between two countries is harmful for environmental policies and mitigating the probability of climate crisis in the political economy, the global democracy model is compared to three variations of the two-country case. Buchholz *et al.* (2005) compares the isolationist case (of one country which implements climate policies unilaterally) against the bargaining case (with an IEA implemented between two countries) to analyse the impact of IEAs on environmental policy. Similarly, this paper compares the global democracy of one voter population with a uniform distribution of beliefs against the Nash equilibrium solution from the best response functions from the two-country case. This result is found in the case of two countries which do not have an IEA but instead reach non-cooperative Nash results with three variations; namely the symmetric country size model, the asymmetric country size model, and the asymmetric bias model.

5.1. Symmetric country size model results

In this model variation, the share of each country's population is approximately symmetric, as the adjustable parameter of relative country size is set to 0.5. The population size in our estimation for country A is 484 and 516 for country B. There is no bias introduced in this model. The kernel density function in Figure 5.1 shows that the beliefs for both countries have approximately the same distribution across optimal probabilities of crisis. The functions overlap almost identically, with minor exception at the left-hand tail and a slight discrepancy at the approximate median value. The median optimal probability of crisis for both countries is approximately 0.45 (Figure 5.1). Therefore, between countries beliefs are not substantially different.

Figure 5.2 shows that when the population is split into two similarly sized populations, each country's best response is to consume at higher levels compared to the global democracy point. The Nash equilibrium point is much higher at $c_1 = 1.2134$ for each country. Thus, the non-cooperative Nash outcome is that both countries consume more in the first period.

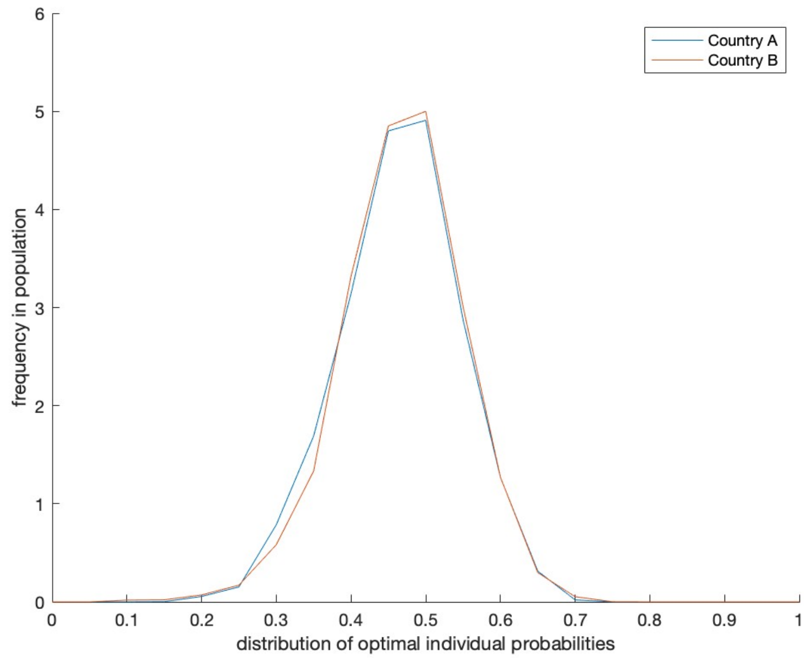

Figure 5.1: Symmetric country size model: Kernel density function of the distribution of the optimal probabilty of crisis and frequency thereof across individuals in country A and country B

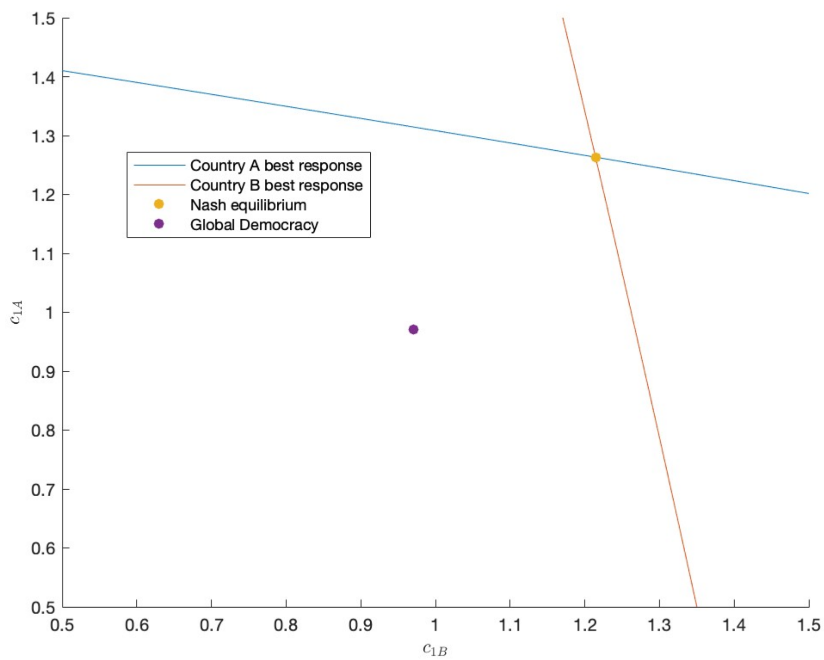

Figure 5.2: Best response functions for symmetric country size model compared to global democracy

5.2. *Asymmetric country size model results*

In this variation of the two-country model, the adjustable parameter of relative country size is set to 0.1. The population sizes in the estimation are 104 in country A and 896 in country B. Figure 5.3 shows that beliefs are substantially similar across the distribution of optimal individual probabilities between countries. Albeit that there are slight discrepancies in the curvature between countries in Figure 5.3, both countries' kernel density functions have the same approximate shape and share an approximate median optimal probability of crisis of 0.45.

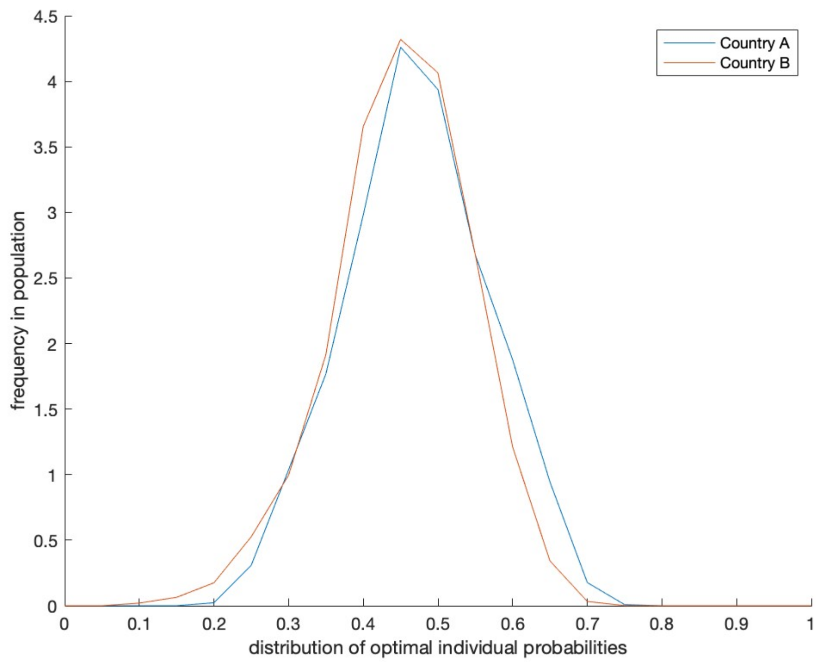

Figure 5.3: Asymmetric country size model: Kernel density function of the distribution of the optimal probabilty of crisis and frequency thereof across individuals in country A and country B

As is shown in Figure 5.4, when country A has a significantly smaller population size it is a best response for country A to consume at the highest threshold $c_{1A} = c_H = 1.5$ that is possible, irrespective of the consumption level that country B chooses. On the other hand, country B's best response is to consume at a significantly lower level of approximately $c_{1B} = 1$ irrespective of what country A consumes. The Nash equilibrium result in the case of a larger country B and a smaller country A leads country A to consume much more than the global democracy case, and country B to consume only slightly more. Notably, country A consumes 0.5 more than country B in the first period, which yields a significant imbalance as a result of a large size difference between the countries.

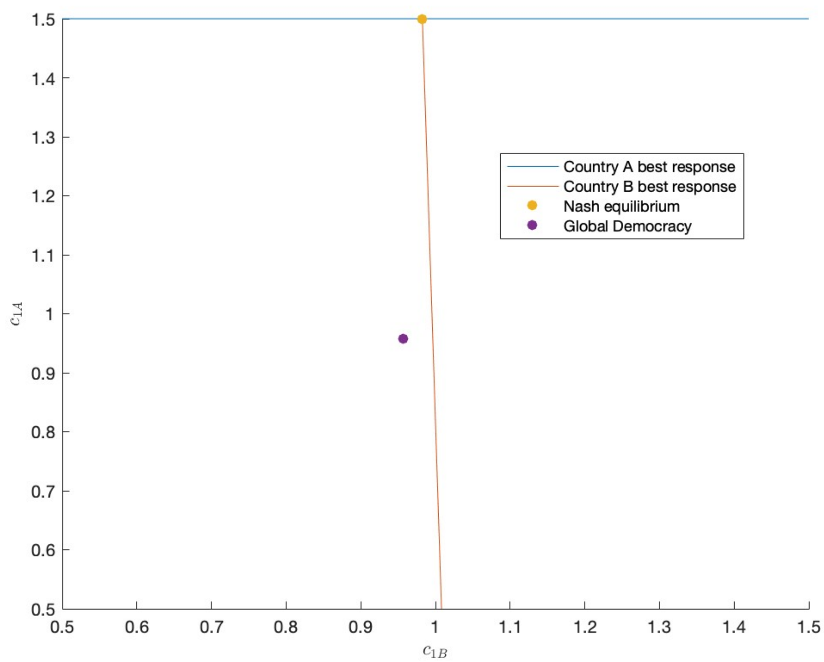

Figure 5.4: Best response functions for asymmetric country size model compared to global democracy

5.3. Asymmetric bias model results

In our final variation model, a change in the adjustable parameter for bias is implemented. Bias is set to a value of 0.9, and increased from a value of zero for the previous two model specifications. The population is kept symmetric (country relative size parameter is set at 0.5) and is 523 for country A and 477 for country B in this estimation. Figure 5.5 shows a significant discrepancy between beliefs in the population of country A and country B. Country A's distribution of beliefs about the optimal probability of crisis have a higher frequency of approximately 6 individuals at the median probability of 0.5. On the other hand, country B's median probability is approximately 0.4 with a frequency of just less than 5. Thus, country B's distribution of beliefs are lower on average compared to country A.

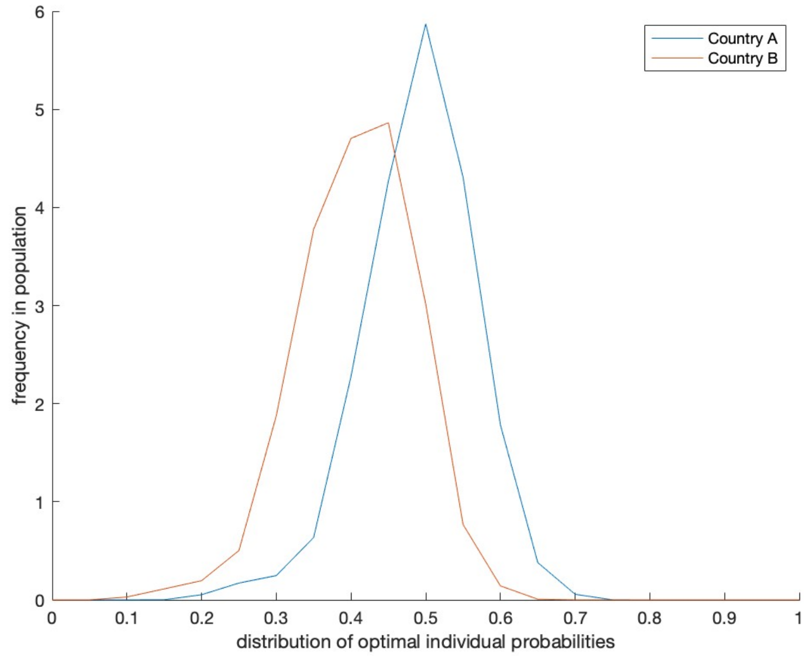

Figure 5.5: Asymmetric country bias model: Kernel density function of the distribution of the optimal probabilty of crisis and frequency thereof across individuals in country A and country B

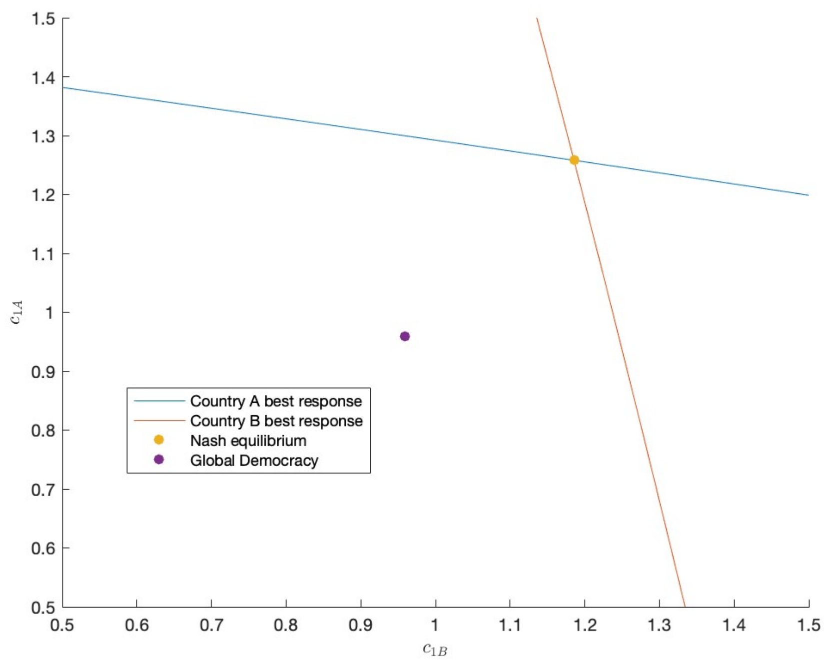

Figure 5.6: Best response functions for assymetric bias model compared to global democracy

Figure 5.6 shows that the best response functions in the non-cooperative case between a country with relatively higher bias and another with unbiased beliefs leads to a much higher consumption level. For both countries in this model, consumption in the first period is $c_1 = 1.2234$.

5.4. Discussion

The main objective of the comparison across model variations is to determine whether imbalances in relative country size and biased beliefs are beneficial or harmful for advancing environmental policy objectives. Buchholz *et al* (2005) reaches an analytical result in which voters may be incentivised to vote for less green candidates in order to improve their own country's bargaining position when there is an IEA. This implies that unless there is full co-operation, any bargaining outcome is bad for environmental policy and the probability of a climate crisis. Besley & Coate (1997) also suggest that non-cooperation with other countries may yield a greater expected utility than if co-operation occurs.

Buchholz *et al.* (2005) provide a possible reason for this "of transboundary pollution, where the economic activities of one country have negative effects on other regions. Since national governments do not take these externalities into account when they decide on their environmental policies, their non-cooperative strategies generally lead to an inefficiently poor state of the ecological system." Buchholz *et al.* (2005) finds that compared to the median outcome, co-operating governments care less about environmental outcomes

Firstly, it is clear from the results discussed that introducing asymmetries between countries related to relative country size and biased beliefs leads to higher period one consumption for both countries in all cases. The extent of increased consumption varies across the different model specifications. Higher consumption levels are only optimal if beliefs are increased and it is believed that the climate crisis will not be too severe.

As evidenced in Table 5.1, the global democracy model's beliefs are approximately equal to the beliefs in both the symmetric and asymmetric country size models. The inability for voters to account for the joint impact of both country A and country B's consumption on the probability of crisis results in voters voting for higher consumption despite it leading to an increased likelihood of crisis. Albeit that both countries would be better off if they consumed less, the best response function for each individual takes the other country's consumption as given only in their decision relating to consumption levels and not related to the probability of crisis. Thus, the Nash equilibrium result that arises from the best response functions of each country is sub-optimal and Pareto inefficient.

Secondly, different asymmetries lead to different consumption imbalances. For the symmetric size model, country A's population of 484 is smaller than country B's population of 516. The consumption levels of country A exceed those of country B, and country A's period one consumption is 1.2601 and country B's period one consumption is 1.0363 (Table 5.1). A similar result arises in the asymmetric size model, where the significantly smaller country A can consume at the highest threshold possible. Therefore, a smaller country has a best response function which yields a greater expected utility for higher consumption levels than for a relatively larger country.

On the other hand, in the asymmetric bias model, country A has a higher population than country B in similar relative proportions as the symmetric size model (country A's population is 523 and country B's population is 477 in the asymmetric model estimation) but country A's consumption level is higher than country B. This can be accounted for due to the higher level of biased beliefs in country A than in country B. Thus, due to country A having more voters that believe that the climate crisis will not be too severe, means it is a best response on average for voters in country A to vote in higher consumption levels than country B. Despite country A believing a higher probability of crisis is optimal, the resultant probability of crisis of 0.7234 is significantly greater than the median belief of the optimal probability of 0.5000 (Table 5.1). Thus, both countries are worse off in this model variation compared to the global democracy case.

Therefore, in these non-cooperative model results it is demonstrated that introducing two-country interdependence yields higher consumption levels for both countries which accordingly increases the probability of crisis which is detrimental to both countries. A higher consumption point as a Nash equilibrium is sub-optimal and welfare-reducing for both countries. Although, the higher probability of crisis that arises for the asymmetric model is not much higher than the global democracy case, as the former has yields a probability of 0.5363 and the latter a probability of 0.4499 (Table 5.1). Therefore, the country with a significantly smaller population and without bias can take advantage of their smaller size to consume at higher levels without incurring a substantially higher risk of crisis.

Whereas, if the country has beliefs which are biased to be higher on average then such a country can consume more than another country. However, the risk of a situation in which countries are approximately symmetric in size and asymmetric in beliefs yields the highest probability of crisis across the model variations considered in this thesis.

Table 5.1: Results for model variations to compare population size, period one consumption, median of beliefs regarding the optimal probability of crisis and the true probability of crisis across four different model variations

	Global democracy	Symmetric size	Asymmetric size	Asymmetric bias
Population size	1000	A 484 B 516	A 104 B 896	A 523 B 477
Consumption	0.9499 1.2234	A 1.2601 B 1.2134	A 1.5000 B 1.0363	A 1.2781 B 1.2234
Median of beliefs	0.4499	0.4500	0.4500	A 0.5000 B 0.4000
True crisis probability	0.4499	0.7134	0.5363	0.7234

Table 5.1 shows that the asymmetric bias model yields both the highest period one consumption for both country A and country B, as well as the highest probability of crisis. Therefore, it seems that the worst outcome across the four models considered is the asymmetric country bias situation. To compare symmetric size and symmetric size in addition to asymmetric bias, the difference in Nash equilibrium probability of crisis is not significantly different; in the symmetric size model the probability is 0.7134 and in the asymmetric bias model the probability is 0.7234. Thus it is worse to transition from an asymmetric country size case to a symmetric country size scenario compared to introducing bias into one country's beliefs when country size remains symmetric.

6. Conclusion

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This thesis has extended the framework presented in Buchholz *et al.* (2005) by incorporating further contributions from the extraction of non-renewable resources literature and the information aggregation in the political economy literature. Specifically, it has developed a simplified numerical model that generates the non-cooperative set of results. These results are derived from a two-country setting in which both countries are democracies with majority voting, and each individual is a possible candidate who may serve as political representative if they win each pairwise comparison across voters.

Instead of simply considering two homogenous and symmetric countries, this thesis introduces asymmetries with respect to relative country size and biased beliefs which were not possible with the analytical approach followed in Buchholz *et al.* (2005). Moreover, private signals and the probability of crisis are introduced into our model to provide more realistic and workable assumptions which provide a model alternative with more descriptive power. Private signals determine individuals' beliefs which dictate their voting preferences. The probability of crisis allows for the realistic possibility that the consumption path in the next period may be non-linear, and may in fact alter the trajectory of the political economy permanently.

To begin to answer the research question of how the political economy may hinder the objectives of IEAs between countries, our comparison across four model variations provides novel insights. The first model specification of the single-population, global democracy serves as our base of comparison and delivers the median voter result; the candidate with that holds median belief about the optimal consumption level and probability of crisis is the winning candidate. In this model, consumption is just below one and the probability of crisis is just below 0.5.

On the other hand, in the non-cooperative results derived from The three model variations illustrate realistic imbalances that exist in the political economy.

The fact that the global democracy case yields the outcome that maximises welfare and keeps the probability of crisis low means that the first problem with IEAs is the lack of cooperation. If countries could fully cooperate, as simulated by the global democracy model, then such a welfare-maximising outcome could be achieved. However, the assumption included in our model pertaining to how best responses are determined for each individual provides insight into why cooperation is not attained.

Individual's best response functions take the other country's consumption as given to determine only the optimal level of consumption, and omit the fact that both countries' consumption levels jointly dictate the true probability of crisis. Instead, the mechanism in our model that leads to these results are that individuals do not fully internalise all the costs and benefits of increasing their consumption levels in the two-country setting. Thus, both countries end up worse off. The three variations in the model (the symmetric size model, the asymmetric size model, and the asymmetric bias model) all result in Pareto inefficient outcomes.

Buchholz *et al.* (2005) suggests to overcome the lack of co-operation, could create mandatory side-payments that must be paid by the country that induces pollution in the other country to the other country to account for the negative externality which would adjust voters and politicians payoffs to consider environmental degradation more directly and thus lead to better co-operative outcomes. But in their model they include the trade-off between domestic product and environmental policies, so would not improve our models outcomes, would require a different specification

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