PRELIMINARY: DO NOT QUOTE

# International Trade and the Feasibility of Global Climate Change Agreements

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## Abstract

Climate change is a classic externality problem that has been analyzed by Shapley and Shubik (1969), Barrett (1994) and others. Their research shows that small players (small countries in our case) have little incentive to participate in cooperative arrangements which either fully or partially internalize externalities. This is because small countries have to undertake costs of their carbon mitigation actions, but being small there result in little improvement in the global climate. Large countries have more incentive to participate as their actions, while costly to them, have a significant impact on global temperature change. This work on externalities also suggests that the core of the game with global warming without transferable utility may be empty.

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# 1 Introduction

We discuss the incentives for individual country participation in global climate change negotiations and what factors,including the presence of international trade, influence country willingness to participate and how. These negotiations are aimed at reducing global warming by countries mutually agreeing to reduce their carbon emissions and in this way jointly internalize the associated global externalities from own country emissions.

Climate change is a classic global externality problem that has been analyzed by Shapley and Shubik (1969), Barrett (1994) and others. Their research shows that small players (small countries in our case) have little incentive to participate in cooperative arrangements which either fully or partially internalizes externality. This is because small countries bear costs of their carbon mitigation actions, but being small the resulting improvements in global climate largely accrue elsewhere. Large countries have more incentive to participate as their actions, while costly to them, can have a significant impact on global themselves via temperature change. This work on externalities also suggests that the core of the game with global warming without transferable utility may be empty.

Here, we present numerical simulation results which bear on these issues. We first discuss the symmetric case with a single consumption good globally in which country endowments may be put aside to reduce global temperature change (i.e. reduce carbon emissions) or consumed. We show that there exists a critical country size such that larger countries are willing to negotiate reduction in carbon emissions while countries smaller than the critical size are not willing to do so. We then investigate non-symmetric cases and explore the role of preferences and other parameters on critical country size for active participation.

We then generalize the analysis to the N good-N country case (one good per country) which allow for the presence of international trade in the analysis. We use this combined Armington trade and global warming model to investigate the impact of international trade on the likelihood of global negotiations occurring to reduce emissions and hence, world temperature change. Trade facilitates positive terms of trade effects from lowered domestic production, enhancing country direct gains from their own actions on global climate change. It also reduces the costs of actions since reductions in consumption are spread over many goods and so the marginal utility of consumption is less adversely affected compared to the one good case.

Our numerical results also show that countries that are not willing to participate in the one good case may be willing to participate in the N good case with international trade. These results therefore suggest that international trade can be a positive factor in motivating international negotiation on climate change.

In a final section we use data on consumption and trade for 7 major world economies (US, EU, Japan, China, India, Russia, Brazil) along with assumed growth profiles for these countries for various damage and temperature change assumptions for a business as usual scenario to make further numerical investigations with our analytical structures. The base data is for the period 2004/2006 with assumed yearly growth rates for different periods. We use calibration for a temperature change function for prospective change in temperature to a business as usual scenario out to 2034 and 2051 and to vary assumptions of associated damage over the ranges reported by Stern (2007) and Mendelsohn (2007). Once again we find that international trade is a positive factor in encouraging international negotiation on climate change, we also show that the incentive to join such negotiations varies greatly with the prospective size of damages.

## 2 Theoretical Analysis-One-good Case with Temperature Change

Global warming negotiations aim at carbon emission abatement in the presence of external diseconomies of own countries active-global negotiations in these vein began in Kyoto 1997, and continue in the current post Bali road map negotiations to conclude in Copenhagen with agreement for the period begin 2012.these negotiations involve joint mutual agreement to act, and only conclude when all parties accept each others commitments. We focus on the incentives to participate in negotiation, rather than the outcome of such negotiations, effectively whether the core of the cooperative game represented by a strategy space over possible actives on climate change is empty or not. In the non-externalities case Debreu and Scarf (1960) established the non emptiness of the core. Debreu and Scarf (1967) showed how in a replica economy the core of the economy collapsed to the competitive equilibrium establishing a form of equivalence between the core and competitive equilibria. Shapley and Shubik (1969), however showed by notes and example that the core of an economy with external diseconomies may be empty. In cases where own agent actions to internalize externalities (reduce carbon emissions) have little own effect (such as with small coalitions), but at substantial cost, there is little incentive to act or join cooperative arrangements. Shapley and Shubik (1969) implicitly discuss a case with non transferable utilities, but where transferable utilities allowed (as in Uzawa (2004)) the non emptiness of the case will be reversed due to the joint gains from internalizations. This suggests that collective agreement on carbon reduction in the case above side payments are not collected and may not be feasible in the global warming area. The number of countries participating in any agreement would need to be small since each country can free-ride without any punishment. We argue below that as we introduce trade between countries, agreement is easier to reach. We start with a one-good case, and then move to the N good, N country case. Empirically based analyses follow later.

## 2.1 Theoretical Model

Assuming there are $N$ countries in the world, each produces the same one good. The output of each country $i$ is $R_i$, and the total output (or potential output) of the world is fixed as $\bar{R}$. The utility of each country is affected by its output as well as the temperature change of the world, $\Delta T$. Without loss of generality, we assume the utility of each country has a simple Cobb-Douglas function form.

$$U_i = U_i(R_i, \Delta T) = R_i^{\alpha} \cdot \Delta T^{\beta} \quad \alpha > 0, \beta < 0 \tag{1}$$

Global temperature change is affected by the change in carbon emissions for each country. We adopt a very simple formulation and assume that emissions are just output times emissions intensity. Define the emissions intensity of country $i$ as $e_i$ .Here we treat it as the power function of emission (not output).

$$\Delta T = g(\sum e_i \Delta R_i) = a(\sum e_i \Delta R_i)^b + c \tag{2}$$

The carbon reduction of each country can be regarded as the reduction of output, which has both negative and positive effects on the utility of each country. On the one hand, the reduction of output will bring down the utility of one country directly; on the other hand, the output reduction lowers emissions and thereby world temperatures and that will improve the utility of *all* countries. Therein lies the externality. However, if the benefits of lower global temperatures is larger than utility loss from reducing consumption a country would be willing to enter into an agreement to reduce emissions and perhaps be willing to unilaterally reduce emissions.

$$\frac{-dU_i}{dR_i} = -\frac{\partial U_i(R_i, \Delta T)}{\partial R_i} - \frac{\partial U_i(R_i, \Delta T)}{\partial \Delta T}\frac{\partial \Delta T}{\partial R_i} \geq 0 \Rightarrow$$
$$MU_i = -\alpha \Delta T^{\beta} R_i^{\alpha-1} - \beta R_i^{\alpha} \Delta T^{\beta-1} a b e_i \geq 0 \tag{3}$$

## 2.2 Calibration of the Model

Our calibration will be done for eight countries, US, EU, Japan, China, India, Russia, Brazil and the rest of the world (ROW.) To begin our work, we need to use the data on output, growth rates and emission intensity to calibrate the model to determine parameters $a$,$b$ and $c$ from equation (2). We will then use these parameters to determine which countries satisfy the condition in equation (3) and thus, are interested in participating in a carbon reduction agreement.

We have the emission data for the year 2004 and will use 2004 as the base year. Since we don't have any way of forecasting emission intensity we make the strong assumption that emission intensity will not change as we move ahead in time. Later we will discuss how relaxing this assumption might affect our findings. The Stern review (2006) forecasts that the "business as usual" (BAU) growth path of emissions will lead to about a $3°C$ increase in average global temperature by the year 2035 and about a $4.8°C$ increase by 2050[1]. We will use this BAU forecast to calibrate our model.

The first step is to compute what emission levels will be in 2036 and 2051 under a BAU scenario. Data and calculations for this exercise can be found in Table 1. The GDP and emissions entries for 2004 are data. Emission intensity, $e_i$, is calculated as emissions divided by GDP is in row three. Row four contains measured GDP in 2006. Row five presents calculated emissions in 2006 using the measures GDP and the emission intensities calculated from 2004 data. Average growth rates from 2000-2006 are reported in row six of Table 1. Row seven has the growth rates we have assumed for our projections. Notice that in most cases we used growth rates slightly below the 2000-2006 average based on the view that these growth rates are probably on the high side for long term growth projections. The eighth row contains the GDP forecasts for 2036 based on the 2006

[1] In Stern review (2006),even if annual flow of emissions keep the current level, the stock of GHG would still reach 550ppm $CO_2e$ by 2050.While in BAU paths, the annual flow of emissions is accelerating, and the level of 550ppm $CO_2e$ could be reached as early as 2035, at which there is 77-99 per cent of chance of global average temperature rise exceeding $2^oC$. if the level of 750ppm $CO_2e$ is reached around 2050, then the temperature change will be up to near $5^oC$.

GDP and the assumed growth rates. Using the assumption of a constant emission intensity row nine gives the emission forecast for each country in 2036. Rows ten and eleven compute GDP and emissions for 2051. So, the result of our calculations is that based on the BAU scenario emissions go from over 36 billion metric tons of carbon in 2006 to about 125 billion tons in 2036 and 266 billion metric tons in 2051. Next, we plug these emission levels into equation (2) to solve for the values of the parameters $a, b$ and $c$.

Using the Table below, we can calculate the following.

**Table 1: GDP and Emission Projections-2036 and 2051 (Trillions US$/Billions Metric Ton)**

| | US | EU | Japan | China | India | Russia | Brazil | ROW | Total |
|---|---|---|---|---|---|---|---|---|---|
| GDP 2004 | 11.712 | 13.044 | 4.608 | 2.254 | 0.667 | 0.592 | 0.664 | 8.048 | 41.590 |
| Emission 2004 | 6.050 | 3.841 | 1.258 | 5.009 | 1.343 | 1.525 | .0332 | 7.880 | 27.241 |
| $e_i$ | 0.517 | 0.294 | 0.273 | 2.222 | 2.012 | 2.577 | 0.500 | 0.979 | 0.655 |
| GDP 2006 | 13.164 | 10.636 | 4.368 | 2.645 | 0.912 | 0.987 | 1.067 | 14.682 | |
| Emission 2006 | 6.800 | 3.132 | 1.193 | 5.877 | 1.835 | 2.544 | 0.534 | 14.376 | 36.289 |
| Actual Growth | 2.657 | 1.956 | 1.652 | 9.568 | 6.833 | 6.745 | 3.104 | 3.662 | |
| Assumed Growth | 2 | 1.5 | 1.5 | 7 | 6 | 6 | 4 | 3 | |
| GDP 2036 | 23.845 | 16.626 | 6.828 | 20.132 | 5.237 | 5.668 | 3.462 | 35.638 | 117.436 |
| Emission 2036 | 12.316 | 4.896 | 1.864 | 44.738 | 10.537 | 14.609 | 1.731 | 34.894 | 125.585 |
| GDP 2051 | 32.092 | 20.786 | 8.537 | 55.545 | 12.551 | 13.585 | 6.235 | 55.522 | |
| Emission 2051 | 16.576 | 6.121 | 2.332 | 123.433 | 25.253 | 35.012 | 3.118 | 54.363 | 266.207 |

As for the temperature change, it can be written as the function of emission change. Here we treat it as the power function of emission (not output). So, we can solve for the values of parameters $a$, $b$, and $c$.

$$0 = a(36.289 - 36.289)^b + c$$

$$3 = a(125.585 - 36.289)^b + c$$

$$4.8 = a(266.207 - 36.289)^b + c$$

which simplify to

$$0 = a(0)^b + c$$

$$3 = a(89.296)^b + c$$

$$4.8 = a(229.918)^b + c$$

Solving these equations for the parameters $a$, $b$, $c$ finding that they are 0.113, 0.690, and 0 respectively. Substituting these values to equation (2), we have:

$$\Delta T = g(\sum e_i \Delta R_i) = 0.113(\sum e_i \Delta R_i)^{0.69} \tag{4}$$

The final step before we can do our calibration is to find values for the parameters in the utility function..We normalize $\alpha + \beta = 1$ . According to the Stern Review (2006), Mendelsohn (2006) and other researchers, the damage cost of emission with business-as-usual (BAU) paths ranges from 1to 20 percent of GDP, which can be treated as utility change of the same proportion and used to calibrate the parameters. We compute the utility parameters that would give rise to each of the possible utility reductions. We use the United States to do this calculation and will assume that preferences are the same across countries.

| Utility Loss | Relative Utility | $\alpha$ | $\beta$ |
|---|---|---|---|
| 1% | 0.99 | 1.07 | -0.07 |
| 5% | 0.95 | 1.37 | -0.37 |
| 10% | 0.90 | 1.75 | -0.75 |
| 20% | .080 | 2.6 | -1.6 |

# 3 Global Carbon Reduction Participation

We are now ready to do our main calibration exercises. We first consider what happens to welfare if each country reduces output by 1%. We use a time horizon of thirty years so the calculation each country makes trades off a permanent reduction of output by 1% against a lower global temperature in thirty years. What we do in each case is to compute the utility change. A positive number means that the benefit of lower temperatures in thirty years is larger than the cost of the output reduction. Hence, that country would presumably be willing to enter into a carbon reduction agreement whereby it agrees to reduce output by 1%.

## 3.1 Autarky Case-2036

The first calculations we make assumes that there is no international trade. The results for the first calibration are below in Table 2. Each row represents the results for different assumptions regarding the utility loss from the BAU temperature increase. Row one assumes a 1% utility loss, row two a 5% utility loss, row three a 10% utility loss, and row four a 20% utility loss. Looking at row one we see that Only the US and China would benefit with a carbon reduction agreement, all other countries suffer a welfare loss. The intuition for this result is that the US and China are relatively large so their reduction in output has a significant effect on global temperatures. Whereas, for smaller countries, the given reduction in output yields little reduction in global temperatures.

Looking at row two if the utility cost of a $3°C$ temperature increase is 5% all countries but Brazil are willing to enter into a carbon reduction agreement. And if the cost rises to 10% then all countries are willing to reduce carbon emissions. This illustrates two points. First, for a given level of damage larger countries are willing to participate than smaller one. Second, the more damage temperature increases cause the more countries are willing to participate.

**Table 2: Analysis for Utility change for 1% decrease in output for each National economy assuming autarky and BAU, 2006-2036**

| | $\beta$ | US | EU | Japan | China | India | Russia | Brazil | ROW |
|---|---|---|---|---|---|---|---|---|---|
| 0.01 | -0.07 | 0.030 | -0.006 | -0.153 | 0.067 | -0.922 | -0.822 | -0.866 | 0.079 |
| 0.05 | -0.37 | 0.567 | 0.419 | 0.212 | 3.9 | 0.627 | 0.834 | -0.352 | 0.907 |
| 0.1 | -0.75 | 1.5 | 1.1 | 0.780 | 18 | 6 | 7 | 1.035 | 2.6 |
| 0.2 | -1.6 | 4.8 | 3.2 | 2.6 | 197 | 67 | 70 | 11 | 11 |

Next, we examine the effect of the time horizon countries use to analyze the problem. As stated earlier, the BAU scenario predicts global temperatures will rise $4.8°C$ by 2050. We do the same calibration as above only for the time period 2006-2051.

### 3.2 Autarky Case-2051

The results for the calibration for the periods 2006-2036 and 2006-2051 can be found in Table 3 below. Values under the A heading are the results for 2006-2036. These results are taken directly from Table 2. Values under the B heading are for 2006-2051. Inspection of Table 3 reveals that the utility values are uniformly higher for the case 2006-2051 than for 2006-2036. Also, if we consider the 2051 time frame under the 1% utility loss scenario the EU joins the US and China as being willing to participate in the carbon reduction agreements. Moving to the 5% utility loss case (and the 10% and 20% cases) all countries are now willing to participate in carbon reduction agreements.

Looking at Table 3 and comparing columns A and B it is clear that the values in B, column indicating the longer time horizon, are larger than the values in column A. This implies that moving to a longer time horizon increases willingness to participate in carbon reduction initiatives .

**Table 3: Analysis for Utility change for 1% decrease in output for each National economy for autarky under BAU, 2006-2036and 2006-2051**

| | US | | EU | | Japan | | China | | India | | Russia | | Brazil | | ROW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| 1% | 0.030 | 0.058 | -0.006 | 0.009 | -0.153 | -0.14 | 0.067 | 0.94 | -0.922 | -0.476 | -0.822 | -0.37 | -0.866 | -0.753 | 0.079 | 0.15 |
| 5% | 0.567 | 0.791 | 0.419 | 0.531 | 0.212 | 0.313 | 3.9 | 16 | 0.627 | 6 | 0.834 | 7 | -0.352 | 0.788 | 0.907 | 1.5 |
| 10% | 1.5 | 2 | 1.1 | 1.4 | 0.780 | 1.08 | 18 | 99 | 6 | 38 | 7 | 39 | 1.035 | 6 | 2.6 | 4.9 |
| 20% | 4.8 | 8.5 | 3.2 | 4.6 | 2.6 | 5.1 | 197 | 2455 | 67 | 729 | 70 | 686 | 11 | 59 | 11 | 27 |

A-2006-2036

B-2006-2051

## 3.3 Trade Case

We next consider the effect of international trade on the willingness of countries to participate in carbon reduction agreements. As before, we assume there are $N$ countries in the world, however assume an Armington structure so that each good produced is different. So we have an .$N$ good$-N$ country model. We use nested CES preferences where the nesting is two stage. Preferences are defined over $\Delta R_i$ and $\Delta T$ with larger $\Delta R_i$ and lower $\Delta T$ give rise to higher utility. We then parametrically vary $\Delta R_i$ and compute the new equilibrium numerically. For each change in $\Delta R_i$ there is a new equilibrium set of prices and new trade volumes and hence a value for $\Delta U_i$. These values are reported in Table 4 below.

**Table 4: Analysis for Utility change for 1% decrease in output for each National economy for autarky and free trade under BAU, 2006-2036**

| | US | | EU | | Japan | | China | | India | | Russia | | Brazil | | ROW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | B | A | B | A | B | A | B | A | B | A | B | A | B | A | B |
| 1% | 0.030 | 0.105 | -0.006 | 0.086 | -0.153 | 0.047 | 0.067 | 0.442 | -0.922 | 0.253 | -0.822 | 0.133 | -0.866 | 0.094 | 0.079 | 0.141 |
| 5% | 0.567 | 0.677 | 0.419 | 0.547 | 0.212 | 0.493 | 3.9 | 4.7 | 0.627 | 3 | 0.834 | 2.8 | -0.352 | 1.3 | 0.907 | 1 |
| 10% | 1.5 | 1.641 | 1.1 | 1.3 | 0.780 | 1.2 | 18 | 20 | 6 | 12 | 7 | 11 | 1.035 | 4 | 2.6 | 2.7 |
| 20% | 4.8 | 5.172 | 3.2 | 3.5 | 2.6 | 3.4 | 197 | 214 | 67 | 101 | 70 | 97 | 11 | 22 | 11 | 11 |

A-no international trade

B-with international trade

Inspection of Table 4 reveals that generally speaking taking international trade into account makes carbon reduction agreements more likely. Comparing the A (no trade) and B (with international trade) one can see from Table 4 that the values in the B column are generally larger than the values in the A column. Higher values indicate more benefits from reducing your own output hence carbon reduction is more likely. The intuition for this result is that reducing output of your good raises its price, thereby improving your terms of trade making carbon reduction more attractive than in the no trade case.

## 4 Conclusion

We have considered the incentive for individual countries to engage in carbon reduction agreements. To reduce carbon emissions a country must reduce its output. This has two counteracting effects. The direct effect of reducing output is that consumption declines and hence utility declines. However, reducing carbon emissions lower global temperatures and that increases utility. We have isolated three factors that make carbon reduction agreements more likely to occur.

First, larger countries are more likely to participate. That is because a given percentage reduction in output will result in a larger reduction in global temperatures the larger the country. Second, longer time horizons lead to greater willingness to reduce output. That is because longer time horizons result in higher global temperatures for any given output profile. Finally, the presence of international trade makes carbon reduction agreements more likely because reducing the output of your export good has a positive term of trade effect which reduced the cost of output reduction.

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