Toward a Framework for Implementation of Climate Change Treaty through Self-enforcing Mechanisms

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Abstract

Global warming caused by accumulation of emissions of greenhouse gases (GHGs) is a public bad, addressing which requires collective action by all the countries of the world. Under the United Nations Convention on Climate Change (UNFCCC), most countries have negotiated the Kyoto Protocol for GHG emissions control to stabilize climate change. Several issues about the Protocol remain unresolved -- first, most of the significant countries are required to take a decision on whether or not to sign such a protocol, which has large-scale implications for their energy and industrial sectors and economic well-being; second, climate change mitigation is a public good entailing that all the countries would stand to gain due to mitigation action taken by a sub-group of one or more countries; and third, there exists no supra-national authority to enforce such a protocol for the individual sovereign nations. Thus, commitment to cooperate on an international agreement on climate change control remains tenuous. Formally, such a cooperative model is likely to be unstable. The paper discusses the pros and cons of the already proposed international cooperative mechanisms toward climate change mitigation and highlights the problem of information revelation, particularly related to the abatement issues. In this context, it attempts to outline a structure of a self-enforcing burden sharing mechanism for climate change mitigation in an incomplete information framework. The mechanism is an adoption of the well-known Vickrey-Clarke-Groves mechanism, widely used in mechanism design theory.

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1. Introduction

The Earth is warming up, and there is now adequate scientific consensus that climate change is happening, and that it is due to anthropogenic activities. A majority of the observed increase in global average temperatures since the mid-20th century is most likely due to the observed increase in human-induced concentrations of pollutants, such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), called the GHGs. The global increases in CO_2 concentration are due primarily to fossil fuel use and land-use change (deforestation, agricultural land conversion), while those of CH_4 and N_2O are primarily find their origin in agriculture (water logging in paddy fields, ruminating bovine etc.) or other industrial activities.

With global warming on the increase, the likelihood that the ecosystem will either adapt or reverse naturally is diminishing. The impact of global warming is and will take the form of changes in hydrological cycles and associated agricultural productivity, extreme weather variations, thermal expansion causing rising sea levels, increase in pests and diseases and species extinction. The impact is likely to be more severe for developing countries. The reasons vary from lack of resources, coping capacities and abject poverty to geographical disadvantage due to location in tropical regions where severe weather will hit the most, and concerns regarding a rise in the sea level in the case of the small island nations.

Most of the countries of the world believe that something needs to be done to tackle global warming and climate change. Since global warming is a global public bad, tackling it requires collective action on the part of all countries. In this context, countries have negotiated a worldwide agreement on GHG emissions control in order to stabilise climate change called the Kyoto Protocol. The Kyoto Protocol was adopted in Kyoto, Japan, on December 11, 1997, and it entered into force on February 16, 2005. A hundred and ninety three parties (192 states and 1 regional economic integration organisation) of the United Nations Framework Convention on Climate Change (UNFCCC) have ratified the protocol to date.

Several issues about the Kyoto Protocol remain unresolved. For instance, most of the significant countries of the world are involved and required to take a decision on whether or not to sign the protocol, which has large-scale implications for their energy and industrial sectors as well as their economic policies in general. Moreover, climate change mitigation is a public good that all countries would stand to gain from. Since such mitigation could result from actions taken by a subgroup of one or more countries, there is a strong incentive for the rest of the world to free ride on countries that take mitigating action. In addition, there exists no supra-national authority to enforce such a protocol for individual sovereign nations. Thus, in the absence of positive net economic benefits to individual countries, no commitment to co-operate with other countries on an international agreement on climate change control is expected to be implementable.

Consequently, the enforcement of the protocol has run into rough weather. Many of the Annex I Parties to the Kyoto Protocol, mainly developed countries who have increased their emissions instead of reducing them as agreed (UNFCCC website), lack credibility.[4] On the other hand, despite the clamour by developed countries that large emerging economies such as China, Brazil and India, must accept binding emission reduction commitments, the latter have taken recourse to developmental arguments or the need to grow and reduce poverty for not accepting these binding commitments. They are willing to take a developmental path that minimises emissions, but given their income levels, the transfer of expensive green technology to them must be facilitated by developed countries, a suggestion generally opposed by the developed countries. Each side believes that it has to bear the costs while the benefits would go to the other and is, therefore, unwilling to take or commit to any mitigation action. In order to break this impasse, it is imperative to focus attention on the incentives that individual countries may have to sign an international agreement on climate change control.

Given the context, the principal aim of this research is to evolve a new framework of self-enforcing climate change mitigation actions and ensuring burden sharing with thrust on the implementation procedure. The self-enforcement mechanism will be established internationally and ensure compliance, driven by the compatibility of the incentive mechanism with individual countries' self-interested goals.

The monograph is organised as follows. Section 2 identifies the major issues in, as well as the current status of, international climate change negotiations. Section 3 provides an international perspective on climate change in terms of policies and actions to mitigate GHGs in the European Union (EU), United States (US), emerging economies and elsewhere, including their experience with the cap and trade systems, carbon taxation, and such like. Section 4 discusses the pros and cons of the proposed international co-operative mechanisms toward climate change mitigation and highlights the problem of information revelation, particularly related to abatement issues. In the concluding section 5, an attempt is made to outline the structure of a new self-enforcing climate change treaty in an incomplete information framework. It also identifies the scope for future work.

2. Major issues in and current status of climate change negotiations

2.1. Current state of play at the international negotiations on climate change

Over the years, nations realised the need to take action to reduce emissions of GHGs, which, apart from natural forces, are a major factor responsible for global warming. The scientific community claims that with the stabilisation of GHG concentration to 450-550 parts per million (ppm) by 2050, the temperature increase could be contained

[4] UNFCCC Website.
http://unfccc.int/files/essential_background/background_publications_htmlpdf/application/pdf/ghg_table_06.pdf

to less than 2°C. The first ever step taken to address this issue was on May 9, 1992, when the UNFCCC was constituted. A further step was taken in this regard on December 11, 1997, when the governments adopted the landmark Kyoto Protocol, which entered into force on February 16, 2005. The protocol imposed varied legally binding emissions reduction targets for industrialised nations and the economies in transition (termed as Annex-I countries), with an average reduction target of 5.2 per cent below the 1990 levels, to be achieved during the period 2008-2012. Countries decided on the individual target shares through a process of negotiations. The nations had to initiate domestic policies and measures that would help cut back their GHG emissions. Besides, the protocol allowed nations to establish innovative mechanisms (such as Joint Implementation (JI), participating in joint projects with developing nations through the Clean Development Mechanism (CDM) and establishing an Emissions Trading (ET) regime (among Annex-I parties)) to enable them to meet their emissions reduction goals through cost-effective approaches. A review of the progress on emissions reduction points out that, during 1990-2006, the emissions in the Annex I countries reduced by around 4.7 per cent. Interestingly, however, the reduction was due to slackening of economic activity in the countries of the former Soviet Union and Eastern Europe (the so called "economies in transition"), as the emissions in the remaining Annex I countries rose by around 10 per cent over the same period.

Since the term of the protocol expires in 2012, a new global climate deal is essential to continue efforts beyond 2012. Developing countries are to play a decisive role in negotiating a post-Kyoto climate agreement. The negotiating governments had envisaged signing a new agreement to replace the Kyoto Protocol during the 13th Conference of Parties (CoP) at Bali, Indonesia in 2007 and the 15th CoP at Copenhagen, Denmark in December 2009 □ a goal that remains largely unfulfilled.

At the Bali UN Summit, the parties to the UNFCCC adopted several agreements pertaining to the post-Kyoto treaty. The thrust was on improving the dissemination of renewable energy technologies, lower emissions and plan lower energy consumption targets. Furthermore, the meeting also led to the creation of an Ad hoc Working Group on Long-Term Co-operative Action (AWGLCA) that aimed to enforce the Convention in participating countries up to and beyond 2012. The AWGLCA has been reporting to subsequent CoPs.

The Copenhagen Summit of 2009 did not achieve a binding agreement for long-term action. What emerged from it was a political accord negotiated by around 28 parties, championed by US, China, India, Brazil and South Africa. The Copenhagen accord was 'noted' by the CoP merely as an external document, which was not negotiated within the UNFCCC process. The document referred to the collective commitment by developed countries for new and additional resources of around US$30 billion for period 2010-12 through international institutions - a promise that has yet to be met.

A key deviation in the approach of the international climate change negotiations that was ushered in by the Copenhagen Summit was a move from a centralised (or top-down) to a more decentralised approach for mitigation action. The Copenhagen Accord emerging out of the deliberations of the summit did not address the issue of assigning specific targets for emissions cuts or a decisive peak year of global emissions. Instead, more than 100 countries committed themselves voluntarily to seek emissions cuts to hold the average increase in global temperatures to below 2°C. The goal itself has been considered somewhat ambitious and there is some scepticism about the ability of countries to realise it (Stern, 2009). Furthermore, the reliance on carbon markets did not find any explicit mention in the Accord. It merely stated the intention to use opportunities for relying on market mechanisms (UNFCCC, 2010). By May 2010, 127 countries had indicated their support for the Copenhagen Accord. Further, 42 Annex I countries and 42 non-Annex I countries have provided information on their intention to adopt measures towards reducing emissions/emissions intensity and other mitigation actions, as agreed under the accord. India, China and other emerging economies (along with developed country partners) have undertaken voluntary pledges to reduce carbon emissions intensity levels by varying degrees. India has pledged to reduce its emissions intensity by 20-25 per cent of the 2005 level by 2020. Chinese has a more ambitious goal to reduce the emissions intensity by 40-45 per cent of the 2005 level, again by 2020. The Brazilian pledge is to reduce emissions between 36-39 per cent of the 2020 business-as-usual level. The US has taken the national position to cut emissions by 17 per cent of the 2005 level, the EU by 20-25 per cent (or even higher) of 1990 level, Russia and Japan by 25 per cent of the 1990 level.

Though the Copenhagen Accord failed to set a new deadline for a legally binding treaty to succeed the Kyoto Protocol, it brought to the fore several important issues. It recognised that global temperature increases should be limited to 2°C above the pre-industrial levels. This would require that emissions be reduced to half their 1990 levels by 2050. Since developing nations need to grow, a significant share of the emissions cut would have to come from developed nations.

There were other significant outcomes of the Copenhagen Summit that have a bearing on future negotiations. The summit demonstrated that there is not a single country or a coalition of countries that would take a lead in initiating climate change policies or have unchallenged influence on the climate change scene. Major GHG emitting nations would always have an incentive to form a bloc and hinder any progress on international climate negotiations and this forms a big obstacle in the development of new mitigation strategies. It also made it evident that existing nations would have to be convinced that any action on their part for mitigating climate change impact would not hinder their economic prosperity, and, hence, reliance would have to be placed on nationally appropriate mitigation action (NAMA). This was coupled with the need for technology transfer and financing mechanisms, which could be propagated to the nations of the world.

Next, the AWGLCA was due to report to CoP 16 at Cancun, Mexico during November 29-December 10, 2010. The Cancun meeting can be considered a step forward in the following respects. First, the Cancun Agreements lay down nationally appropriate mitigation targets and actions (as in the Copenhagen Accord) for around 80 countries – including significant GHG emitters such as China, the US, the EU, Brazil and India, by the year 2020. In this respect, the meeting also came up with agreements on the mechanisms for monitoring and verification that were laid out in the Copenhagen Accord and that now encompass international consultation and analyses of developing country mitigation actions. Second, the agreements also progressed on plans for tropical forest protection (the so-called Reduced Deforestation and Forest Degradation, or REDD+), by establishing a scheme under which wealthy countries could help prevent deforestation in poor countries by possibly working through market mechanisms. Next, there was the official UN Agreement to hold the temperature rise below a global average of 2°C. And finally, the agreements set up the so-called Green Climate Fund to provide financing for mitigation action and technological adaptation, with the World Bank as the interim trustee of the Fund. Specifically, it is envisaged that developed countries would mobilise $100 billion annually by 2020 to support mitigation efforts and technology adaptation in developing countries, which would include public and private sources (that is, carbon markets and private finance), bilateral and multilateral fund flows, as well as the Green Climate Fund.

2.2 Key issues for future negotiations

There is a huge challenge in addressing global climate change by arriving at multilateral arrangements among all major economies to moderate and/or reduce GHG emissions. Though the Kyoto Protocol imposed binding commitments on Annex I countries to reduce their emissions during 2008-2012, one has witnessed a steady erosion of the coverage of the emissions. The original Kyoto Protocol covered ~ 66 per cent of 1990 industrial CO_2 emissions. However, with the US not ratifying the agreement and a decline in the relative emissions of rich countries, the Kyoto Protocol presently includes countries that comprise only ~ 27% of global emissions. Large emerging economies such as China, India or Brazil have not been willing to accept any obligatory reduction commitments since this may not be inconsistent with their growth and development aspirations. Besides, the principle of "common but differentiated responsibility" acknowledges that these countries are allowed to have their emissions grow to catch up with the economic level of developed countries. On their part, the developed countries have been clamouring for an agreement that includes all the major emitters, including large emerging economies such as China and India, to undertake significant mitigation commitments to make any mitigation effectual at the global level. The discussions at the Copenhagen Summit and thereafter, point toward the fact that these concerns are likely to persist during the discussions of the post-2012 climate effort.

Achieving international co-operation to address climate change has become an onerous task given the strong free-rider incentives. Being a global public good, everyone benefits from climate change mitigation, while only those who undertake it have to bear the mitigation cost. Co-operation is potentially difficult to implement given the sovereignty of participating nations, the absence of a supra-national authority to impose emissions targets and significant side-payments obligatory to make such co-operative endeavour feasible. Besides, if co-operation is linked to other issues, such as trade restrictions or border tax adjustments, it undermines economic efficiency. Interestingly, the feasibility of achieving a socially desirable outcome through full cooperation is derived from the threat that no coalition will benefit if the grand coalition of countries breaks into singletons when any coalition breaks away from it. However, the threat that countries will break into singletons if one or more countries leave the grand coalition may not be credible (see Wood, 2009 commenting on the results in Chander and Tulkens, 1997). What has been witnessed is the formation of parallel climate blocs or countries. The experience of the 2009 Copenhagen Summit negotiations is illustrative of some of these concerns.

Therefore, there is the need to seek out mechanisms to engage large developing nations in voluntary or self-enforcing mitigation activities in the forthcoming negotiations, given their reluctance to accept binding emissions reduction commitments and given the constraints on the information environment (regarding individual countries' costs of abatement and preferences for environmental quality) in which the negotiations are being held.

3. An international perspective on climate policies

As can be understood from the earlier discussions, the presence of an externality in the production or consumption activities of both industry and households gives rise to a wide-range of environmental problems. The inadequate pricing of environmental goods results in the failure of the market system. Existing markets can no longer correct for the distortions arising from pollution and the level of pollution is much higher than is socially desirable. Two broad types of policy instruments available to correct the externality problems are command and control measures (CAC) and market-based instruments (MBIs). The CAC measures consist of standards and norms imposed by regulatory authorities to improve environmental quality. The MBIs, on the other hand, consist of taxes/ subsidies/tradable pollution permits/economic incentives, all of which mainly work through getting the relative market prices right. Carbon taxation and emissions trading are the two most commonly prescribed MBIs worldwide to mitigateGHGs and climate change.

Market-based climate policy instruments play a crucial role in market economies for combating challenges posed by climate change. If an accurate price is put on GHG emissions and markets are effective in transferring this price signal to the decision-making processes of companies and individuals, there will be an efficient allocation of limited resources and emissions targets will be met at the lowest cost. However, successful implementation of these instruments will need that the government adopts a certain policy mix for its effective functioning. Some of the commonly used MBIs that put a price on GHG emissions are levying a unit tax, creating a carbon market or providing subsidies. Although, taxation is the most commonly suggested, there remain several challenges in making use of environmental taxation. If the marginal abatement costs are assumed to be high or involve high uncertainties, setting the right tax level is a very complex issue.

An alternative and effective solution for curtailing GHG emissions is emissions trading. This involves a cap-and-trade approach, where the desired level of emissions is first defined and then used to establish an overall cap on the emissions from a system. Emissions certificates equal to this cap are issued. Participants are required to hold certificates to cover their emissions in a given period and are penalised for non-compliance. So, they face the choice between implementing emissions reduction measures and buying emissions certificates in order to comply. The price of the certificates in the market is determined by the interaction of demand and supply and it represents the implicit price of GHG emissions. The trading of emissions rights amongst nations is expected to lead to equalisation of the permit price and the marginal abatement cost across countries and hence, result in an economically efficient outcome. Emissions trading would also help address international equity concerns in GHG mitigation.

The following discussion covers the experience with carbon taxation and the cap-and-trade mechanism as an instrument used for mitigating environmental pollution in select OECD countries. This will help in understanding the key characteristics of tradable permit schemes used in each of these nations and in providing insights into the lessons learned from the world-wide use of cap-and-trade mechanism to enable their use in future climate change mitigation.

3.1. Carbon taxation and abatement subsidies

Among the prevalent market-based policy options to reduce GHG emissions, carbon taxes and emissions abatement subsidies have gradually emerged as cost-effective and efficient instruments over a period. A tax or a subsidy puts a price on the GHG emissions by internalising the environmental and social cost of global emissions in the price of the product. Hence, it results in an economically efficient means of combating global GHG emissions. Taxing the carbon content of the fuel acts as an incentive to reduce its consumption and promotes the development of innovative energy-reducing technology, which would further result in lower emissions.

In US, the usage of carbon tax as an effective emissions reduction instrument has percolated down to the local level. The city of Boulder in Colorado (in US) implemented the tax on carbon emissions from electricity in April 2007. Similarly, Quebec, the second largest province in Canada also levied a carbon tax on petroleum, natural gas and coal in October 2007. British Columbia introduced their carbon taxation in 2008. Energy taxes in Europe were introduced initially to raise budget revenues and control oil imports. However, this changed during the 1980s, when gasoline taxes in Europe were used to meet the environmental objectives. Finland was one of the first countries to levy a carbon tax in 1990. This was followed by the imposition of the carbon tax by Sweden (in 1991), Netherlands (in 1996), Germany (in 1998) and UK (in 2000) to curb GHG emissions. The European Commission proposed the first EU-wide carbon tax in the year 1992 (The Reality of Carbon Taxes in the 21st Century, 2008). However, this proposal and many more such attempts made were rejected by the EU member states. In 2005, with the adoption of an Emissions Trading Scheme (ETS) in the EU, there was no more interest among member states to use carbon tax as an emission control device.

With the uncertainties associated with the cost of reducing emissions, a tax could prove to be a more efficient incentive-based option in tackling the global climate change problem. If the level of the tax could be co-ordinated among the major emitting nations, the global emissions reduction target could be achieved at a minimum possible cost. Climate change problem arises from the accumulation of CO_2 in the atmosphere over a span of time. A steadily rising tax would help accommodate the cost fluctuations (arising from the variations in the cost of cutting emissions each year) by providing firms higher incentives to cut down larger emissions when the cost is low and cut down on emission reduction when it is costly.

However, one must also make a note of the fact that there are a few shortcomings of using carbon tax as an effective method to combat global emissions. It is extremely difficult to judge accurately the impact of a carbon tax on GHG emissions or the time frame over which its effect would be realised. Its success in reducing emissions depends on whether the tax has been able to raise the price of fuel to such an extent that it significantly reduces consumer demand for GHG emitting products and how effective it has been in developing innovative low-energy using technologies. The rate of emission reduction may also be rise to the extent that tax revenues are used to fund future research or other programmes that help achieve additional emission reductions.

3.2. Cap-and-trade mechanisms

3.2.1. US

Rising pollution costs in the US raised the demand for cost-effective instruments to lower environmental pollution. Among the several proposals for curtailing GHG emissions, the national cap-and-trade programme for limiting and reducing carbon emissions seems to have emerged more prominently in the US as compared to an emissions tax. Similar to a carbon tax, the cap-and-trade scheme has the effect of imputing a price on carbon. Tradable permits are considered effective market-based policy instruments, which, if designed appropriately and implemented properly, would encourage firms to undertake pollution control efforts in their own interest and help meet collective policy goals. The environmental policy makers also prefer tradable permits to an emissions tax for a variety of reasons. As opposed to an emissions tax, a tradable permit helps regulators conceal the explicit cost of environmental protection from the consumers. It helps reduce emissions instead of simply reallocating them among different sources. A permit scheme specifies the quantity of pollution reduction to be achieved in contrast to the indirect and uncertain effect of pollution taxes.

Under a cap-and-trade system, the total permissible level of pollution is established and allocated among the polluting firms in the form of tradable permits. Those firms, which are able to restrict their emissions below the permitted levels, could sell their surplus permits to other polluting firms. The most successful environmental protection permit programme in the US has been the SO_2 allowance trading programme for acid rain control introduced under the Clean Air Act Amendments of 1990. The programme had huge benefits arising from the positive human health impact of decreased local SO_2 and particulate concentrations.

3.2.2. The European Union

The ETS has been used intensively in the EU and its experience provides valuable lessons to other countries. It was the world's first cap-and-trade program for CO_2 emissions. Besides the similarity in terms of establishing an absolute cap on CO_2 emissions, the EU-ETS differs from the US cap-and-trade systems for other emissions in terms of the distribution of tradable allowances. The key characteristic of the EU-ETS system is its decentralised approach (Ellerman and Joskow, 2008) in allocating emission allowances (permits) across member states and in creating institutions for monitoring and managing emissions allowances. This gives much of the authority for decision making to the member states. In this milieu, the member states themselves decide on the individual cap levels, allocate their allowances (permits) across sources, create institutions to monitor, report and verify their emissions and make choices on some structural features such as banking, auctioning etc. Each member state has a fixed endowment of carbon emissions (whose sum total equals the Kyoto Protocol target for EU), which is allocated between the trading and the non-trading sectors of the member states depending on the abatement costs. Thus, the EU-ETS comprises an overall cap on total emissions (equal to the EU commitment under the Kyoto Protocol) from all sectors of the economy across all the member states. The central EU authority (the European Commission) then specifies the "trading "sectors that participate initially in EU-ETS. The central authority has the objective of minimising the total abatement costs subject to the emissions endowment constraints of the member states.

Since around half of the EU emissions remain in the non-trading sectors, there have to be some controls on the sources in these sectors as well. Each member state has its own emission target, which it addresses using the National Allocation Plan (NAP). NAP has the two-fold task of allocating the total emissions between trading and non-trading sectors of the economy and specifying how the permits in the trading sector will be distributed among the individual sources. Under the EU-ETS, the central authority determines the demand for allowances by specifying the participating sectors in the economy. Supply is determined jointly by the decisions of the individual member states. The EU experience indicates that an ETS could be an effective tool, which could be modified over time for combating GHG emissions.

The EU-ETS is not free from criticism either. One criticism of the EU-ETS system focuses on the high profits to the electricity sector that resulted from the free allocation of allowances and over-allocation of emission permits. Nonetheless, this experience has guided other national governments (such as Australia, New Zealand and Japan) to rely on cap-and-trade mechanisms for reducing GHG emissions. Some of the issues that need to be addressed while setting up the trading mechanism in a region are specifying an adequate period for regulation prior to the start up, setting up efficient financial institution to help firms achieve their emissions reduction goal and a good emissions database to set targets.

4. The pros and cons of non-cooperative and co-operative mechanisms toward climate change mitigation by countries

International co-operation among countries is often deemed necessary to cope with global pollution, since outcomes related to laissez-faire equilibria turn out to be socially inefficient. This is because, under purely decentralised market-based regimes, each country chooses its pollution behaviour, ignoring the cost imposed on other countries as a result of its behaviour. That is, global warming and climate change, due to GHG emissions, is a classic case of global public bad, such that the adoption of non-co-operative optimal behaviour by countries derived from non-internalisation of damages inflicted by a country's pollution on other countries leads to excessive pollution generation as compared to a socially desirable outcome. This is the implication of the classic divergence between social and private optima.

In this section, we first define the social optimum of the global climate game. Next, we highlight the inefficiency of the non-co-operative Nash outcome in comparison with the social optimum. As an alternative, coalitional or membership games, relying on both co-operation and non-co-operation are analysed, along with the difficulties associated with such solutions. The focus then shifts to a discussion on the problems of information asymmetry that underlines the need for self-enforcing incentivised mechanisms for climate change mitigation.

4.1. The social optimum

In case of global pollutants such as GHGs, the disutility or damage from pollution suffered by each country is dependent on the sum of pollution generated by all countries put together. In a static setting, let the set of countries be denoted by, $N =$

$1, 2, \dots, n$. Further, let p_i be the pollutant emissions of country i. One could characterise the social optimum as the vector of polluting emissions that yields highest net benefit at the global level. The social optimum can be achieved within this framework with the strong (or heroic!) assumption of a fully enforceable co-operative mechanism that can achieve the social optimum through an appropriate treaty for all countries. The equilibrium is the solution to net utility maximisation exercise:

$$\max_{\{p_1, p_2, \dots p_n\}} \sum_{i \in N} u_i = \sum_{i \in N} b_i (p_i) - \sum_{i \in N} d_i \left(\sum_{j \in N} p_j\right), \quad (1)$$

where $u_i(.)$ is the net utility derived by country i, $b_i(.)$ is the gross benefit or utility from a country's own emissions, and $d_i(.)$ denotes own damage resulting from the sum of emissions from all n countries. It is assumed that $b_i^{'} > 0$, $b_i^{''} \leq 0$, $d_i^{'} > 0$, and $d_i^{''} \geq 0$. That is, while both benefits and damages are increasing in the level of pollution, the former is increasing at a non-increasing rate, while the latter rises at a non-decreasing rate. These assumptions are standard in marginal cost-benefit analysis. Here, emissions are viewed as inputs into production or consumption in the benefit function, b_i, which is subject to diminishing returns, while damages are increasing as more pollution gets generated due to the limited assimilation capacity of the environment.

Solution to (1) yields the first-order condition as

$$b_i^{'}(p_i) = \sum_{i \in N} d_i^{'} \left(\sum_{j \in N} p_j\right), \forall\, i \in N. \quad (2)$$

This requires that the marginal benefit of pollution for country i is equated to the global marginal costs that are equal across all the countries. Simultaneous solution to an equation such as (2) for each country i yields the socially desirable pollution vector, which we denote by $p^S = (p_1^S, p_2^S, \dots . p_n^S)$. As implied by (2), each country chooses its pollution so as to equate its marginal benefit from pollution to the aggregate marginal cost for all the n countries put together.

However, socially desirable outcomes such as those characterised by the condition in eq. (2) are normative equilibria that are almost non-existent in real economies, thus making it near impossible to enforce any form of global co-operation in a basic static setting such as the one described here. This is because any strategy to co-operate, conditional on co-operation by other countries, is never rewarded. That renders it irrational for a country to co-operate. This motivates the analysis of non-co-operative outcomes in the international climate change game (Finus, 2003).

4.2. Non-co-operative behaviour and climate change

Climate change can be visualised as a special case of the Prisoner's Dilemma game, wherein each country strategically decides on how much to pollute, given the pollution by other countries. That is, the maximisation behaviour of a single country takes as given the emissions of the remaining countries. The Nash equilibrium that emerges can be referred to as the status quo, before an international environmental agreement (IEA) is signed (Finus, 2003).

Again, with p_i representing the emissions of country i, the net utility/benefit, u_i, for the ith country is expressed as

$$u_i = b_i(p_i) - d_i\left(\sum_{j \in N} p_j\right), \tag{3}$$

where functions $b_i(.)$ and $d_i(.)$ are as defined earlier.

The Nash non-co-operative equilibrium is worked out by solving

$$\max_{p_i} u_i(p_1, p_2, \ldots p_i, \ldots p_n)\ \forall\ i \in N, \tag{4}$$

that yields the first-order condition to be

$$b_i^{'}(p_i) = d_i^{'}\left(\sum_{j \in N} p_j\right). \tag{5}$$

This implies that the marginal benefit of pollution is equated to own marginal cost by each country i. Implicitly solving (5) derives the non-co-operative level of pollution generated by the ith country as a function of pollution levels of all the remaining $(n-1)$ countries, or $p_i = f_i(p_{-i})$. This constitutes the best-response function of the ith country, or its best reply, given the emissions of the remaining countries. We would thus have n such functions, one for each country in the set N. Notably, the slope of the best response function will be derived as

$$\frac{dp_i}{dp_{j \neq i}} = \frac{d_i^{''}}{b_i^{''} - d_i^{''}} < 0,$$

in view of $b_i^{''} < 0,\ \ d_i^{''} > 0$. Thus, as expected, the best response to an increase in the emissions by any country j is that country i will be induced to reduce its emissions. The simultaneous solution of these best response functions will yield the vector of pollution levels $p^{NC} = (p_1^{NC}, p_2^{NC}, \ldots . p_n^{NC})$ at the non-co-operative Nash equilibrium, which are lower than the 'no-abatement equilibrium' that assumes a complete disregard for any damage/disutility from pollution, p^{Max}. That is, the vector p^{Max} results as the $\arg\max u_i = b_i(p_i)$, by all i.

Nevertheless, aggregate emissions (here) are higher than what is socially desirable, since no country recognises the damages that its own emissions would inflict on other countries. In this sense, Nash non-co-operative outcomes are considered as sub-optimal. The other assumptions that form the basis for a non-co-operative game are complete information about each country's benefits and costs and the absence of a central authority that could allocate and enforce pollution rights on countries. In real economies, both these assumptions do not hold. First, typically countries of the world do communicate and take co-operative decisions on enforceable agreements, such as the Montreal Protocol (to deal with ozone depleting substances) and the Kyoto Protocol (to tackle the problem of global warming and climate change due to GHGs). Second, information asymmetry in the form of absence of information by participants to the treaty about each other's benefits and costs of pollution may lead to incentives to misreport their preferences and/or abatement costs for pollution cleanup. In respect of the first, the analysis in the paper has been extended to consider coalition formation to incorporate the role of binding commitments as part of an international climate treaty, such as the Kyoto Protocol. This is included in Section 4.3. The second of these concerns, namely, those relating to information asymmetry that render such co-operation difficult, constitute the centrepiece our paper and is discussed in Section 5 of the paper.

4.3. International coalitional games of climate change

Analytical models of coalitional games have been utilised in the context of climate change under both co-operative and non-co-operative game theoretic framework. Typically, a co-operation-based coalitional model is distinguished from the one that is based on non-co-operation, first, by its focus on what the group of countries can achieve in terms of emissions abatement as part of a binding agreement than on what the individual players can do and second, by the fact that co-operative behaviour ignores how the group of countries/players in the coalition function internally. Alternatively, when the possibility of coalition formation is modelled as a non-co-operative game, one must specify how the coalitions form and how the individual member countries choose joint actions (Osborne and Rubinstein, 1994). Typically, as will be explained below, while co-operation based coalitions derive from the aggregate worth of a coalition (or what the aggregate payoffs for the coalition are), those from non-co-operative behaviour obtain from individual payoffs. Further, in case of co-operative climate regimes, the worth of a climate coalition is based on the actions of those inside the coalition wherein these actions are distinguishable from those who are outside it. In comparison, the value or the payoffs of the individual non-co-operation based climate blocs are drawn from the same guiding rules or principles. In addition, while co-operation based coalitions rely on the concept of a Core (defined below), the non-co-operative games of coalition formation function on the premise of internal and external stability. A more formal exposition of these aspects is presented below.

4.3.1. Co-operation and concept of Core

If N_1 denotes a subset of countries forming a climate coalition or climate bloc and N_2 is the set of countries that lie outside the climate bloc such that $N_1 + N_2 = N$, then the worth of the coalition N_1 can be defined by the characteristic function, w, which is

$$w(N_1) = \sum_{i \in N_1} u_i(p_{N_1}, p_{N_2}), \tag{6}$$

with the emissions vector p_{N_2} following from some assumed action taken by the countries outside of the climate coalition, while N_1, N_2 and p_{N_1} are derived by solving the maximisation problem for the countries in the climate bloc; that is,

$$\max_{p_{N_1}} \sum_{i\in N_1} u_i\left(p_{N_1}, p_{N_2}\right). \qquad (7)$$

The expression in (6) means that the worth of the coalition is the total payoff that is available for division amongst the members of the climate bloc N_1.

The notion of stability of a coalition in this case is embodied in the concept of the "core". The idea of the core is analogous to that of the Nash equilibrium of a non-co-operative game, that is, an outcome is stable if no feasible group-deviation is profitable or no sub-coalition can deviate and do better for its members. In general, for an $n-$player coalitional game with transferable utility, defined by a set of players, N, and a characteristic function, w, the Core is defined as $C(N, w)$ such that

$$C(N, w) = \left\{\pi \in R^n: \sum_{i\in N} \pi_i = w(N) \text{ and } \sum_{i\in N_1} \pi_i \geq w(N_1) \forall N_1 \subseteq N\right\}, \qquad (8)$$

where $\pi = (\pi_1, \pi_2, \ldots \pi_n)$ is an $n-$ dimensional imputation. An imputation is defined as an "efficient" and "individually rational" distribution of the payoff of the grand coalition, a single coalition with all the n players as members.[5] That is, the Core is the set of imputations in which no coalition has a value greater than the sum of its members' payoffs. Therefore, no coalition has the incentive to leave the grand coalition and receive a larger payoff (Osborne and Rubinstein, 1994; Wood, 2010).

In the specific circumstance of a global climate change treaty, one shall be concerned with the grand coalition (N) implementing the socially desirable emissions vector. Accordingly, if $\pi^S = (\pi_1^S, \pi_2^S, \ldots \pi_n^S)$ defines the imputation at the socially desirable emissions vector, p^S, and t_i is the transfer such that $\sum_{i\in N_1} t_i = 0$, and $\pi_i^* = \pi_i^S + t_i$, then an imputation $\pi^* = (\pi_1^*, \pi_2^*, \ldots \pi_n^*)$ lies in the core if $\sum_{i\in N_1} \pi_i^* \geq w(N_1)\ \forall\ N_1 \subseteq N$ (Finus, 2003).

Accordingly, the focus of analysis in Chander and Tulkens (1997) is on the γ-core. They characterise the co-operative game where a subset N_1 of countries denotes the climate coalition, which maximises its collective benefit, while N_2 is the set of countries that lie outside the climate bloc and act non-co-operatively. Then, following the notion of payoff described in (6), the payoff or utility of the climate bloc will be:

[5] Efficiency implies that the aggregate payoff exactly distributes the total value, or $\sum_{i\in N} \pi_i = w(N)$, and individual rationality entails that individually the distributed payoff is at least as high as what a player could obtain on its own, or, $\pi_i \geq w(\{i\})\ \forall i \in N$.

$$w_\gamma(N_1) = \sum_{i \in N_1} u_i\left(p_{N_1}, p_{N_2}\right), \tag{9}$$

where p_{N_1} and p_{N_2} are the emissions of the climate bloc and sum of emissions of countries outside the bloc respectively. The core of the associated game will be the set of possible payoff vectors for the countries in the grand coalition where no coalition will benefit if the grand coalition dissolves into singletons (or individual countries) when any coalition or individual country breaks away from it. Thus, all countries are singletons and maximise their individual payoffs, as in the Nash equilibrium. The payoff of a country i depends upon its emissions as well as the transfers t_i received by it such that $\sum_{i \in N_1} t_i = 0$. Thus,

$$\pi_i = b_i(p_i) - d_i\left(\sum_{j \in N} p_j\right) + t_i. \tag{10}$$

It is shown by Chander and Tulkens (1997) that the γ-core is non-empty if the transfers are chosen such that

$$t_i = b_i\left(p_i^{NC}\right) - b_i\left(p_i^{S}\right) - \frac{d_i'(\sum_{j \in N} p_j^S)}{\sum_{k \in N} d_k'(\sum_{j \in N} p_j^S)} . \left[\sum_{k \in N} b_k(p_k^{NC}) - \sum_{k \in N} b_k(p_k^S)\right]. \tag{11}$$

with superscripts NC and S denoting the non-co-operative and socially optimal outcomes respectively, the first term in the right hand side of (11) is payment to be received by a country as compensation for the loss of utility that it will suffer in moving from the Nash equilibrium to the social optimum. The second term is the payment made by each country in proportion to the fraction of marginal damages in it to the total marginal damages in all the countries covering the total decrease of benefits included in the square brackets (due to a move from the social optimum to the non-co-operative outcome). Thus, according to (11), a country that gains more from emissions reduction in the form of reduced marginal damages also bears a larger opportunity cost of co-operation.

The concept of a core such as the one described above is criticised in at least two significant respects (Finus, 2003). First, the core carries a normative notion as it focuses on the first-best or the most efficient outcomes. Thus, it does not explain real world phenomena such as formation of sub-optimal coalitions or climate blocs such as those that have emerged lately, namely the emerging economies of BRIC countries together with the US, small island states etc. at the Copenhagen Summit. Second, while the transfer scheme is useful in the context of a heterogeneous set of countries, the transfer formula provides an incentive to countries to misreport their abatement costs and environmental preferences. Since the payments depend on the fraction $\frac{d_i'(\sum_{j \in N} p_j^S)}{\sum_{k \in N} d_k'(\sum_{j \in N} p_j^S)}$, countries may have the incentive to bias their estimation downward, while with the receipts depending on the loss of benefits, captured by the difference $b_i\left(p_i^{NC}\right) - b_i\left(p_i^{S}\right)$, countries might tend to overstate this loss or utility to receive higher compensation. This leads us to seek out alternative forms of coalitions based on non-co-operative behaviour.

4.3.2. Coalition formation as a non-co-operative game

In comparison with the above, if one assumes the emergence of several coalitions, say M number of coalitions, with the structure $C = \left(C_1, C_{2,\dots,} C_{K,\dots,} C_M\right)$, then the value function of country i that belongs to a coalition, say C_K, can be expressed as

$$v_i(C_K, C) = u_i(p^{NCC}) + t_i, \tag{12}$$

where $p^{NCC} = (p_1^{NCC}, p_2^{NCC}, \dots, p_K^{NCC}, \dots., p_M^{NCC})$ is the equilibrium vector of pollutants emitted by each coalition $C_K \in C$ (with NCC denoting the non-co-operative coalitions outcome) by maximising the total payoff of countries belonging to the coalition, that is,

$$max_{p_K} \sum_{i \in C_K} u_i(p_K, p_{-K}) \tag{13}$$

and t_i is the transfer paid or received by country i based on a decided transfer mechanism. Notably, the emissions vector p_{-K} follows from all coalitions outside of C_K maximizing maximising their individual payoffs.

Non-co-operation based coalitions pre-suppose stability as put forward by d'Asperemont et.al (1983) implying both internal and external stability of the cartel. These concepts of stability underlie the works of Carraro and Siniscalco (1991, 1993), Barrett (1994, 1997), Carraro (2000) and Finus (2001), which rely on either Nash-Cournot (simultaneous move) or Stackelberg (sequential move) behaviour by countries who participate in the international climate treaty versus those who do not participate.[6] Internal stability entails that no member or participant of the coalition has the incentive to leave the coalition to become a non-member while external stability implies that no non-participant finds it profitable to become a member of the coalition.

More formally, with payoff of coalition C_K^* defined as above, where a participant $i \in C_K^*$ and a non-participant $j \notin C_K^*$, and with the coalition structure given by $C = (C_K^*, 1, 1, \dots 1)$, where C_K^* denotes the coalition of countries, while other countries do not form a coalition but remain singletons, then stability is characterised by the following:

Internal stability: $v_i(C_K^*: C_K^*, 1,1, \dots 1) - v_i(i: C_K^* - 1, 1,1, \dots 1) \geq 0 \forall i \in C_K^*$ that implies that there is no incentive for a member country to leave the climate coalition.

External stability: $v_j(j: C_K^*, 1,1, \dots 1) - v_j(C_K^* + j: C_K^* + j, 1,1, \dots 1) \geq 0 \forall j \notin C_K^*$, which means that there is no incentive for a non-member country to join the climate coalition.

[6] More precisely, a simultaneous move game assumes that the choice of emissions by the participants and non-participants is made concurrently in time; the sequential game is premised on a sequential choice of emissions such that the participants are the Stackelberg leader and non-participants are Stackelberg followers.

Finus (2003) evaluates the premise of internal and external stability and claims that the internal stability of a coalition derives from the notion of profitability for all the participants as compared to the status quo and of joint welfare maximisation of the climate coalition. However, in the face of heterogeneity of countries and need for operating side payments (as transfers), there is less support for the premise of joint welfare maximisation through co-operation amongst countries of the world. Furthermore, the notion of self-enforcing international climate treaties rests on the premise of weak punishment in that as a member country leaves the coalition, the others merely hang on together and re-optimise their strategies. This is indeed corroborated by real world experience of the limited scope for punishment (as compared to the core) and is likely to reduce the effectiveness of climate change treaties. Finally, the notion of stability rests on the assumption of complete information. In reality, the problems of information asymmetry between countries, about costs of climate abatement or environmental preferences, persist. This makes it necessary to turn attention to self-enforcing mechanisms for climate change mitigation that would explicitly incorporate such information constraints. In this sense, mechanisms that address information constraints may yield pollution outcomes that are worse than those under full co-operation as these tend to be second- or third-best, to say the least. The design of self-enforcing climate change in the face of information issues constitutes the focus of discussion in the next section.

5. Self-enforcing framework to implement social optimum: a mechanism design approach

We reconsider the global emissions framework as introduced in Section 4. As has been discussed, the sharing of burden/costs of lowering GHGs to mitigate global warming is a typical case of public goods provision, and as conjectured by Samuelson (1954), there exists no resource allocation mechanism that can ensure a fully efficient level of this provision. There is little incentive for individual countries to take account of the global pollution created by gross emissions by all countries. The key parameters that affect an individual country's decision regarding emissions are the direct effect of the emission reduction on its cost of production (or emissions abatement) or utility/ benefits. These parameters address the aggregate costs incurred to reduce the negative impact of emissions. Analysis of these types of costs is not rare in environmental economics, especially in the context of public goods provision. A common example is the costs associated with cleaning up an oil spill. Henceforth, we focus only on the emissions abatement costs and call the parameter the "clean-up cost" of emissions.

Clearly, the clean-up cost of a country depends on the technologies available to it, cost-effectiveness etc. Therefore, it is understandable that information regarding the clean-up cost of a country may not be readily available to other countries, that is, the clean-up cost of a country is very much its "private information" (we will also call it "type"). As already pointed out in Section 4, when each country pursues its own welfare maximisation, the resulting outcome deviates from the socially optimum outcome. A natural question that arises is whether it is possible to co-ordinate the actions of all countries such that they not only consider their individual clean-up costs, but also endogenise the "public bad" nature of emissions into their decision-making. If we believe that there is an international regulatory authority to enforce such a social optimum, we must also assume that the authority has adequate information regarding the clean-up costs of all the countries needed to achieve emissions reduction in an efficient manner. This is because the authority must minimise the total cost inflicted on the global society by the aggregate emissions of all countries. This total cost must internalise the cost on the global society from emissions *apart from* the clean-up cost of individual countries. The main hurdle the regulatory authority faces is lack of information about clean-up costs of individual countries. The only "non-strategic" approach could be just to ask the countries to report their clean-up costs. But, there are enough reasons to believe that the countries *will not report truthfully*!

To put it intuitively, since the clean-up costs of all the countries are unknown to the authority and is not directly verifiable, each country would try and strategise its reporting in its favour.[7] In other words, if asked to report its clean-up cost, a country will have a wide range of possible values to report from. It is very likely that if the country reports an incorrect value for its clean-up cost, the country is better off!

It is, therefore, not sufficient to constitute a regulatory authority (e.g. supra-national institution) even with consensus among all the countries. Although countries agree on tackling the global pollution emerging from their individual actions, enforcement remains difficult (to say the least!) as each country finds it beneficial to be strategic and report "not truthfully".

The entire scenario demands a solution concept, which can *strategically* enforce or implement the socially optimal outcome, that is, can eke out the private information from the countries by providing appropriate incentives for doing so and by proving to be adequately adverse for not doing so! This requires use of tools from game theory with a framework leading to an objective outcome for every possible parametric configuration or type-vector of countries (characterised by clean-up costs, pollution damages and such like). We also require this entire set-up to be such that it works with no external assumptions, but with a built-in process. This is a reasonable demand placed on the mechanism, as the existence of a supra-national authority is both difficult to achieve and entails a lot of "not so much economic" factors. We would rather abstain from this difficulty and would be happier with the framework being self-enforcing. Thus, ultimately we arrive in the domain of what is called a *Mechanism Design* problem! Mechanism design provides a framework for the analysis of allocation mechanisms (for example, a public good such as climate change mitigation) with

[7] Each country would have the incentive to either misreport (understate) its willingness to pay or overstate its costs of pollution abatement, so as to reduce its own share of aggregate clean-up burden.

specific focus on problems associated with incentives and private information. In our specific context of climate change mitigation, the allocation mechanism will be proposed to be adopted at the international level and ensure compliance that will be driven by the compatibility of allocation rules with individual countries' self-interested goals.

In the next sub-section, we introduce the formal model. Thereafter, we demonstrate the divergence between the social and private optima, given the information problems outlined above. Lastly, we provide a simple self-enforcing mechanism that implements the social optimum while ensuring that countries report truthfully without overstating clean-up cost or understating emissions.

5.1. The Model

We closely follow the set-up introduced in the last section. To formalise the above structure as a tractable model, we make a couple of assumptions. We assume that there is only one homogeneous form of pollution arising out of emissions and we assume that it is possible to put a value on the environmental damage from the aggregate level of emissions. Like earlier, let $N = (1, 2, \ldots., n)$ denote the set of all countries. Also, let $E = (P_1, P_2, \ldots., P_n)$ denote the emissions vector that specifies the emissions levels by all the countries in N. Let D be the social damage or social cost function that captures the global cost inflicted by the emissions by all the countries. Thus, $D(P)$ denotes the total damage value, where P is the total or aggregate worldwide emissions, i.e. $P = \sum_{i=1}^{n} P_i$. It is assumed that $D^{'}(P) > 0$ and $D^{''}(P) > 0$. These assumptions regarding the cost functions are standard in economics literature. We note that D denotes the *overall* damage to the world. Thus, even though countries do vary in terms of being affected by climate change, function D captures the "public bad" aspect of it, namely, the cost borne by the entire world.[8]

Let $C(P_i, \Theta_i)$ denote the clean-up cost incurred by the ith country, where P_i is the emissions by the ith country and Θ_i is a parameter indicating clean-up technologies available with the ith country. Naturally, the cost incurred to wipe out the negative effects of emissions depends on (a) the amount of emissions (P_i) and (b) the technologies (including advancements and innovations which are mainly dynamic in nature) or equipment available and favourable environment (Θ_i). Clearly, Θ_i captures all the information that is private in nature and unknown to all except the ith country. We also assume that $\partial C / \partial P_i < 0$ and $\partial^2 C / \partial P_i^2 > 0$. The first assumption depicts that the clean-up cost rises as the amount of pollution falls. The second assumption implies that the marginal clean-up cost rises as the amount of emissions by a country rises. We

[8] That is, the cross-country differences in pollution damages are not ruled out.

reiterate that both the determining factors, P_i and Θ_i, are known to the ith country. More concretely, countries know their respective clean-up cost functions.[9]

5.2. Social optimum and private optimum

Consider a laissez-faire economy with clean-up cost function $C(.,\Theta_i)$. With no regulation on its emissions, the country chooses an emissions level P_i that minimises its cost, i.e. the clean-up cost $C(P_i,\Theta_i)$. This is given by simple optimisation condition:

$$\frac{\partial C}{\partial P_i} = 0 => C(\overline{P_i},\Theta_i) = 0 \tag{10}$$

Thus $\overline{P_i}$ is the optimal level of emissions that the country chooses to emit when there is no regulation.[10] We now characterise the social optimum in this framework. To reach a socially optimal (or efficient) level of emissions, we need to minimise the total cost inflicted by all the countries put together, i.e.

$$\underbrace{\mathrm{Min}}_{P_i}\ [D(P\,(\theta)) + \textstyle\sum_{i=1}^{n} C(P_i(\theta),\Theta_i)] \quad \text{subject to } \textstyle\sum_{i=1}^{n} P_i(\theta) = P, \text{ for all } \theta. \tag{11}$$

Clearly, the solution to (11) requires finding out an emissions vector $\overline{\overline{P_i}}$ such that it is obtained by solving the following expression:

$$\left[\frac{\partial D(P)}{\partial P_i}\right] + \frac{\partial C}{\partial P_i} = 0 \ => \frac{\partial C}{\partial P_i} = -\ \frac{\partial D(P)}{\partial P_i} \tag{12}$$

Since in (12), $D'(P) > 0$ and $\frac{\partial C}{\partial P_i} < 0$ when evaluated at $\overline{\overline{P_i}}$, it must be that $\overline{P_i}(\Theta) > \overline{\overline{P_i}}(\Theta)$. This shows that private optimal emissions are higher than the socially optimal level. This is very much in conformity to what we have argued so far and captures the effect of emissions as a global public bad while computing the global socially optimal outcome.

While we have justified our requirement for a self-enforcing framework that elicits truth telling from the respective countries and establishes a socially optimal outcome, we have not said much about the economic frameworks that will make it achievable. Next, we give a brief overview of such frameworks or Mechanism Design theory.

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[9] Notably, clean up costs may be beset with uncertainty. However, the paper abstracts from issues of uncertainty in clean-up costs and instead focuses attention only on the issues of asymmetry of information of these costs across countries.

[10] This is analogous to the unbounded emissions characterised in the last section, but now by taking into account information asymmetry on clean-up costs.

5.3. The mechanism design problem

Implementation theory deals with group decision-making processes under various information structures. The objective of this theory is to structure the strategic interactions of the agents in a group so that their actions lead to a socially desirable outcome in each "state of the world", which in our case will take the form of optimal GHG emissions abatement. The group's collective objectives are specified by a social choice rule that selects a set of alternatives from the available set in every state of the world. A classic example is the one of building a public good or project by a public authority. The authority needs to compare its cost to its social benefit. For this, the authority needs to know all agents' valuations for the project. But these valuations are private information of the agents and unknown to the public authority. Implementation theory attempts to design a game-form such that in every state, the equilibrium actions of the agents, according to a pre-specified equilibrium notion, lead to a socially desirable outcome in that state, that is, they belong to the image-set of the Social Choice Correspondence (SCC) in that state. Information available to the agents but unknown to the planner will affect the socially desirable outcome. The formulation of the problem, therefore, must use game-theoretic solution concepts that are appropriate for agents' behaviour and consistent with the informational assumptions. The literature on implementation considers a wide range of equilibrium notions. In the "complete information models" (such as those discussed in Section 4), it is assumed that all agents know the state while the mechanism designer/ regulator does not. A natural notion of equilibrium in this context is Nash equilibrium (Maskin (1999)). Other notions that are consistent with this information setting and that have been studied include the iterated elimination of weakly un-dominated strategies (Moulin (1979)), sub-game perfect Nash equilibrium and various other Nash equilibrium refinements.[11]

In a private information setting, each agent has private information about his/her type and a state is the set of types of all agents. The mechanism designer does not have information regarding the state. Further, an agent only knows its own type but is unaware of types of other agents. In this setting, solution concepts such as Nash implementation or iterated elimination of dominant strategies are inapplicable. This is because an agent is unable to predict the actions of the other agents regarding the elimination of strategies.

A natural notion (amongst others) in this setting is *dominant strategies*. An agent never loses if it uses a dominant strategy at a particular state without thinking about strategies chosen by others.[12] This solution concept is also quite robust with respect to the

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[11] Since every agent knows the types of the other agents as well, they would conjecture the possible actions taken by the other agents. Natural notions of equilibrium in this set up would arise from this pattern of rational behavior by all agents and thus iterated elimination of weak strategies or sub-game perfect equilibrium (in a more dynamic setting) are appropriate in this case. Nash equilibrium of course remains an important equilibrium concept, given its self-sufficient property by definition.

[12] If a mechanism implements a social choice function in dominant strategies, then the direct mechanism is *dominant strategy incentive compatible.*

information environment amongst the countries/players. In the current setting, we also aim to devise a mechanism, which can implement (in dominant strategies, that is, using dominant strategies at every possible state) socially optimal outcomes in the global emissions game. The following discussion focuses on one such mechanism.

5.4. A self-enforcing mechanism

We consider a setting where countries can communicate with the regulator the optimal outcome in the global emissions game (existence of a regulator may be virtual here, as it is not essential to have a real institution that acts as a regulator or planner here) but cannot with one another. We consider schemes where the countries have been asked to report their types in terms of their emissions abatement costs, that is, Θ_is. Suppose the scheme also involves a *tax payment* to be made by each country, based on the vector of announced types ($\hat{\Theta} = \widehat{\Theta_1}, \ldots, \widehat{\Theta_n}$) and the emission level chosen by that country. The aim is to design the scheme in such a manner that each country finds it *not beneficial* for her to announce a wrong type! Thus, the transfer payment function for the ith country would depend on the announced type $\widehat{\Theta_i}$, announcements by the other countries $\widehat{\Theta_{-i}}$, and emission level by the country i, i.e. P_i.

We describe the scheme again: countries are asked to report their respective types, Θ_is. They are also informed beforehand (that is, before they announce their types) that based on their announcement vector $\hat{\Theta}$, each country would pay a tax. We note that the tax payment made by a country *may not* be positive. The novelty of this piece of research would lie in cleverly designing the tax payment function such that each country is incentivised to tell/reveal the truth about its type.

First, we define the social choice function as the rule that maps into optimal (or *efficient)* levels of emissions for a type vector. This implies that, given that the set of countries' true types is Θ, allowable emissions are set at $\overline{\overline{P_i}}(\Theta)$, for all $i \in N$. If the announced type vector is $\hat{\Theta}$, the outcome is $\overline{\overline{P_i}}(\hat{\Theta})$. But this does not complete the description of the social choice function, as it needs to also specify the rules for the tax payments. We note that the trick lies in constructing the tax functions. This is because tax is the only channel through which the net payoffs of countries are adversely affected by higher emissions. The other part of the net payoff is the clean-up cost, which pushes the country to choose away from the socially optimal outcome.

In particular, the cost function of an individual country i, whose true type is Θ_i but announces $\widehat{\Theta_i}$, (and other countries are announcing Θ_{-i}) is $C(\overline{\overline{P_i}}, \Theta_i) + T_i(\overline{\overline{P_i}}, \widehat{\Theta_i}, \Theta_{-i})$, where $\overline{\overline{P_i}}$ is the *efficient* emission level chosen by the country i. If a mechanism enforces "truth-telling" by the countries, then we must have:

$$C\big(\overline{\overline{P_i}}\big(\widehat{\Theta_i}, \Theta_{-i}\big), \Theta_i\big) + T_i(\overline{\overline{P_i}}\big(\widehat{\Theta_i}, \Theta_{-i}\big), \widehat{\Theta_i}, \Theta_{-i}) > C(\overline{\overline{P_i}}(\Theta), \Theta_i) + T_i (\overline{\overline{P_i}}(\Theta), \Theta_i, \Theta_{-i})$$
$$for\ all\ i \in N$$

The left hand side of the inequality is the clean-up cost of country i and the tax paid when the true type of the country is Θ_i and the announced type is $\widehat{\Theta_\iota}$. Thus, this is the cost of the country while lying. The right hand side is the cost when the country is telling the truth. Naturally, telling the truth becomes the dominant strategy if the above inequality holds for any P_i and any possible announcement vector by the other countries Θ_{-i}.

This is a case where an adaptation of the classic Vickrey-Clarke-Groves mechanism (VCG) would be applicable to elicit truth telling as the dominant strategy for each country (Clarke (1971), Groves (1973)). We state the main result in the next proposition:

Proposition: If $\bar{\bar{P_\iota}}$ be an efficient emission function and, for each country i, there exists a transfer function $T_i(\theta) = A_i(\Theta_{-i}) + \sum_{j \neq i} C\left(\bar{\bar{P_j}}(\theta_i, \Theta_{-i}), \Theta_j\right) + D\left(\bar{\bar{P}}(\theta)\right)$, then $(\bar{\bar{P}}, T_i)$ is dominant strategy incentive compatible.

Proof: The mechanism is as follows the countries announce their types, i.e. θ_is and the mechanism yields the levels of emission allotted to each country (given by $\bar{\bar{P_i}}$) and taxes (given by T_i). We prove the proposition by the method of contradiction. Let $(\bar{\bar{P}}, T_i)$ be not dominant strategy incentive compatible. Thus, there exists $i, \theta, \widehat{\theta_\iota}$ such that

$$C(\bar{\bar{P_i}}(\theta), \theta_i) + A_i(\Theta_{-i}) + \sum_{j \neq i} C\left(\bar{\bar{P_j}}(\theta_i, \Theta_{-i}), \Theta_j\right) + D\left(\bar{\bar{P}}(\theta)\right) >$$

$$C(\bar{\bar{P_i}}(\widehat{\theta_\iota}, \theta_{-i}), \theta_i) + A_i(\Theta_{-i}) + \sum_{j \neq i} C\left(\bar{\bar{P_j}}\left(\widehat{\theta_\iota}, \Theta_{-i}\right), \Theta_j\right) + D(\bar{\bar{P}}(\widehat{\theta_\iota}, \theta_{-i})).$$

Or,

$$\sum_{i \in N} C(\bar{\bar{P_i}}(\theta), \theta_i) + D\left(\bar{\bar{P}}(\theta)\right) > \sum_{i \in N} C(\bar{\bar{P_i}}(\widehat{\theta_\iota}, \theta_{-i}), \theta_i) + D\left(\bar{\bar{P}}(\widehat{\theta_\iota}, \theta_{-i})\right)$$

But this violates the efficiency of $\bar{\bar{P}}$!

Hence, we prove that the direct revelation mechanism implements the efficient social choice rule in dominant strategies. This is an application of VCG mechanism. This mechanism has been used for many practical purposes including combinatorial auctions, replica placements etc.

5.5. The pros and cons: research ahead

The tax function introduced in the last section induces each country to tell *the truth,* irrespective of the announcements made by other countries. Thus, it is a *dominant strategy* for the country to tell the truth regarding the type Θ_i. The underlying principle is the same as the VCG mechanism, famous in Mechanism Design theory. We observe that the tax payments by an individual country depend on the social cost of gross pollution as well as on the (clean-up) costs inflicted on *other* countries from *optimal* emissions calculated at the announced cost-type vector. It will be interesting to simulate numerically the model with an arbitrary data set for a group of countries and to show how it works. However, we wish to address this problem in our future research.

The only negative aspect of the VCG model is the assumption made by Clarke (1971) and Groves (1973) that there exist no income effects on the demand for better environment quality (in the context of this research). In other words, the VCG mechanism elicits truth telling about clean-up costs as a dominant strategy and the aggregate level clean-up of GHG emissions is at the socially desirable level when the utility function is quasi-linear. As part of our future research, one needs to seek out alternative adaptations of the VCG mechanism that would apply to a broader class of utility functions. Further, the transfers are not necessarily balanced, that is, the aggregate tax revenue may not add up to the aggregate costs of emissions abatement. This motivates a research question — characterisation of the tax functions in the model discussed above. It will also be interesting to find out what could be the practical implications of these tax payments. Most importantly, however, the framework, in principle, works *without the physical presence of a supra national authority.* Thus, a group of countries, with honest intention (at least in the negotiations round!) conforming to the mechanism designed above, must end up implementing the *socially optimum outcome*! Also, this is true for *any* number of countries and irrespective of the types of countries. The solution concept here is also quite robust, because the optimal strategies of all countries are *dominant* strategies, which are independent of a country's knowledge regarding the types (e.g. technologies available) of other countries. Thus, we overcome the difficulties faced in other solution concepts alluded to earlier.

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