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İriş, Doruk

Sogang University

15 September 2015

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Doruk İriş*
Sogang University

September 15, 2015

Abstract

In the standard emission problem, each country's ruling party decides on an optimal level of emissions by analyzing the cost and benefit to the country. However, such policy decisions are often influenced by political parties' incentives to be elected. Voters tend to give higher priority to economic issues than they do to environmental ones. As a result, political parties have additional incentives to reach a critical economic benefit level, at a cost of higher emission level, in order to satisfy voters' expectations in economic issues. Therefore, this study explores the implications of political parties being averse to insufficient economic performance relative to a critical economic target level on sustaining an international environmental agreement on emission levels. In doing so, we allow countries to have asymmetric concerns about economic targets, as well as asymmetric technology levels. We find that stronger concerns about economic targets deter the most cooperative emission levels countries could jointly sustain. Furthermore, technological asymmetry could either deepen or offset this impact. These results suggest that efforts on achieving substantial international environmental agreements should be supported at the citizen level to eliminate the adverse effects.

Keywords: Emission Problem; Economic Targets; Loss-Aversion; International Environmental Agreements; Repeated Game.

JEL classification: Q50; Q58; D03

Politics is too serious a matter to be left to the politicians.

—Charles de Gaulle

1 Introduction

In many economic models, we assume that governments make optimal choices for their country by taking into account the benefits and the costs to the country. However, in reality governments' objectives often differ from their countries', since they have additional incentives to be re-elected. In this paper, we argue

*dorukiris@gmail.com; Phone: +82-2-705-8505; Sogang University, School of Economics, 121-742, Seoul, S. Korea.

that similar situation also exists when governments decide on their emission cuts. It is widely known that political parties consider economic benefits to be of greater importance, since these benefits are more visible and certain to voters than are the results of environmental policies.[1] As a result, they would have additional incentives to introduce some populist policies in order to achieve some economic targets. Political parties could perceive these targets as critical levels below which voters would be unsatisfied with the economic performance. Furthermore, political parties would be averse to perform poorly in these economic aspects, since it might cost them the next election. For example, an increase in tax, say on gasoline, could be better for the country but not eventually implemented due to such distortionary incentives of the ruling party. In this paper, we aim to understand the implications of such possibly relevant incentives on international environmental cooperation.

To model this, we assume that political parties perceive economic benefits from emission not only in absolute levels but also as gains or losses relative to their economic targets, and that they are averse to insufficient economic performances. More specifically, economic targets are reference levels such that, if a country's economic benefit from emissions is higher than its economic target, then its leaders find the economic performance sufficient (i.e., a gain). However, if the benefit is less than its economics target, then its leaders find the economic performance insufficient (i.e., a loss). Thus, this paper introduces the widely used phenomena of reference levels and loss-aversion into the international environmental cooperation.

Kahneman and Tversky (1979) argue that people perceive outcomes as gains and losses relative to a reference level, which may be current assets, the status-quo, or expectations, rather than final wealth or a welfare level. Furthermore, people exhibit loss-aversion, which is the tendency to strongly prefer avoiding losses to acquiring gains. The theory of loss-aversion has been employed to provide insight into various phenomena such as in financial markets (Benartzi and Thaler, 1995), consumption and saving behavior (Bowman et al., 1999), housing markets (Genesove and Mayer, 2001), voter behavior (Alesina and Passarelli, 2014) at the individual level; and also, in international trade (Freund and Ozden, 2008) and political parties' election platform changes (Schumacher et al., 2015) at the government level.

More specifically, Schumacher et al. (2015) explain why governments change their election platform more than opposition parties. They argue and find empirical evidence that parties with low aspiration change more when they are in government than in opposition due to loss-aversion. For example, when the German Green Party moves into office first time as the coalition partner of Social Democratic Party in 1998, they changed its platform significantly. In short, the economic issues became more important, while the environmental ones became less important. Even though it costed the party some activist and many loyal voters, it was able to remain as an attractive coalition partner and achieved highest nationwide votes ever.[2] In additional to Schumacher et al. (2015), Simon (1985) also argues that political parties exhibit bounded rationality, especially when decisions are complex. Bendor et al. (2011), in their recent book on behavioral theories of election, show that political parties and/or voters' aspiration (reference) levels

[1] For instance, the following link describes recent surveys that show how voters' prioritize economic issues more highly than they do environmental issues in the United States. `http://www.pollingreport.com/prioriti.htm`

[2] See the supporting information provided in Schumacher et al. (2015) for more detailed political history of the German Green Party.

influence party competition, turnout, and voters' choices of candidates.

Alternatively, political parties can be rational. Still, similar impacts on achieving economic targets can be observed if they take actions to maximize not only the net benefit to the country, but also their own private interests (Besley, 2006; Persson and Tabellini, 2000). Rational political parties may be reluctant to change to greener policies if voters are averse to economic losses (Alesina and Passarelli, 2014), or if they are influenced by special interest groups (Grossman and Helpman, 1994). In the latter case, parties may strive to reach an economic target because of industrial lobbyists, who are possibly stronger than the green lobbyists, expecting some economic targets to be achieved.[3] As a result, to be elected, political parties would value the economic benefits from emissions more highly in order to satisfy some economic targets, thus, to attract voters or special interest groups.[4]

Several studies examine how behavioral economics can advance the science of environmental and resource economics, and note that loss-aversion could be crucial for non-market valuations (Shogren et al., 2010) and whether climate change is framed as a loss or a gain (Gsottbauer and van den Bergh, 2013). To the best of our knowledge, İriş and Tavoni (2015) is the only other study (a work in progress), which employs loss-aversion to examine international environmental agreements. They investigate the impact of loss-aversion with respect to a threshold amount of environmental damage, which is viewed as indicative of an approaching catastrophe. Our study differs significantly from that of İriş and Tavoni (2015), because the latter focuses on coalition formation, and particularly the size of coalitions and the types of countries that form a coalition in the case of asymmetry in their beliefs on environmental safe operating limits (references) and in their perceived vulnerability when a threshold is exceeded (loss-aversion).

A country's economic target could be determined, among others, by its past performance and targets, current and expected future performances, performances of other countries, and political parties' declarations. For instance, overly-optimistic declarations might cause ambitiously high economic targets,[5] and while economic busts lower the voters' expectations, it also raises attention in economic issues relative to environmental ones and, thus, can increase the economic targets.[6] In this paper, we assume countries' economic targets and economic target concerns (i.e., how much are targets valued comparing to the benefit and the cost of emissions and, how averse political parties are to insufficient economic performances) to be exogenous and allow them to differ between the countries. Furthermore, we also allow countries to differ in their development levels, particularly in their technology levels. In this context, a

[3]Dietz et al. (2012) study the implications of domestic lobbying, particularly on IEAs. See also Oates and Portney (2003) for a review of lobby groups on environmental policies.

[4]Buchholz et al. (2005) provide a theoretical examination of the implications of the electoral process for IEAs, and find significant adverse effects. Based on empirical evidence, Cazals and Sauquet (2015) show that political leaders' levels of commitment to IEAs differ with the timing of elections. In our model, we abstract completely from the electoral process and focus on the potential consequences.

[5]Miler (2009), using personal interviews with political elites and a quasi-experimental design, finds that politicians often use decision heuristics and suffer from over-optimistic forecasts. Similarly, Frankel (2011) studies the forecasts of real growth rates made by official government agencies in 33 countries. He finds that forecasts have a positive average bias and that this bias is even stronger in economic booms.

[6]For instance, public polls show that voters prioritize economic issues and neglect environmental ones more during 2008 crisis.
http://www.people-press.org/2015/01/15/publics-policy-priorities-reflect-changing-conditions-at-home-and-abroad/

technologically advanced (developed) country needs to emit less than a (developing) country that is not as technologically advanced in order to generate the same economic surplus.

To address the consequences for IEAs of economic targets and loss-aversion, we develop a dynamic game in which countries face a free-riding public goods problem and attempt to maintain cooperation in their national emission strategies. Here, emitted pollution is assumed to be transboundary. We restrict our attention to IEAs that are self-enforcing, as in Ferrara et al. (2009) and Hadjiyiannis et al. (2012), since there is no supranational authority to enforce environmental policy mechanisms. In this context, a country prefers to sustain cooperation on agreed-upon emission policies, as long as the discounted future welfare losses from a breakdown in international environmental cooperation outweigh the one-time gain of a unilateral deviation from the cooperative path. Note that we abstract completely from any participation considerations, which have been at the center of IEA literature (Barrett, 1994; Carraro and Siniscalco, 1993; D'Aspremont et al., 1983; Hoel, 1992).[7] Instead, we look for the sustainability of a cooperative emission level, particularly the most cooperative emission level, by countries aiming to achieve their economic targets and that are averse to economic losses, within the context of a self-enforcing IEA involving full participation. We compare the sustainability of a cooperative emission level by different set of countries that vary in terms of their economic targets, economic target concerns, and technology levels. We examine sets of countries that are both symmetric and asymmetric in terms of these characteristics.[8]

We find that if a country has stronger economic target concerns, that is, it values its economic targets more and/or becomes more averse to economic losses, then this country finds it more difficult to sustain cooperation, but that this situation facilitates the sustainability in other countries owing to strategic substitutability of emission levels. In the case that all countries have stronger economic target concerns, sustaining an agreed-upon cooperative emission level might become easier for some sufficiently developed countries but harder for some developing countries. So, an agreed cooperative emission level could not be sustained after all countries having stronger economic target concerns if there is no transfer mechanism.

Furthermore, we show that a decrease in a country's ability to sustain cooperation means the most (lowest) cooperative emission level this country can sustain increases. Thus, the most cooperative emissions countries can sustain can be ordered as follows: lowest in the case that no country cares about economic targets; all countries reach their targets; and highest if no countries reach their targets.

We also find that it is more difficult to sustain a cooperative emission level if countries become more asymmetric in their technology levels. In this case, the impact of further asymmetry in the level of economic target concerns is ambiguous. Asymmetry in economic target concerns may correct the negative impact of asymmetry in technology levels on sustaining cooperation if developing countries have weaker and developed countries have stronger economic target concerns. Otherwise, it enters as another obstacle for countries to support a greater degree of international environmental cooperation. These results

[7] See also the following more recent reviews of the literature: Barrett (2005) and Finus (2008).

[8] Much of the literature on IEAs examines the case of symmetric countries. However, some studies provide a theoretical examination of countries that are asymmetric in terms of their size and marginal damage from pollution (Kolstad, 2010), marginal costs and benefits of abatement (McGinty, 2007; Pavlova and de Zeeuw, 2013), and technologies (Mendez and Trelles, 2000).

provide another perspective on why leaders have to be further motivated for greener policies by citizens when they are to negotiate in the international arena.

The remainder of this paper is organized as follows. Section 2 sets out the basics. Section 3 characterizes the static Nash equilibrium of our model. Section 4 analyzes the dynamic game. Section 5 provides two numerical analysis: the first one studies the impact of economic target concerns on the most cooperative emissions. The second one analyzes the model for technologically asymmetric countries, gives insights of North-South model. Finally, Section 6 proposes concluding remarks and relates the predictions of our model to the ongoing U.N. Climate Summits. The appendix contains some calculations and all the proofs of propositions and lemma 1.

2 The Model

We assume the world consists of n countries.[9] The countries have perfect information about the world, and decide simultaneously on an emission level of a pollutant substance, $x_i \in (0,1)$. Emissions have a negative environmental effect and give rise to negative externalities owing to transboundary effects. In other words, emissions in country i pollute the environment in country i, as well as in other countries. However, emissions are unavoidable for production, which creates surpluses for producers and consumers. Our model builds on the work of Mendez and Trelles (2000) and incorporates countries' economic targets into the problem. The net-benefit function for country i, which also aims to reach its *economic target*, is as follows:

$$B_i(x_1,...,x_n) = b_i(x_i) - p_i(x_1,...,x_n) + \gamma_i t_i\left(x_i, b_i^R\right), \tag{1}$$

where country i's economic benefit $b_i(x_i)$ depends only on its emissions, the cost of pollution $p_i(x_1,...,x_n)$ depends on all countries' emission levels, and the target utility $t_i\left(x_i, b_i^R\right)$ depends on the country's emissions and economic target b_i^R. The scaling factor $\gamma_i > 0$ measures how much country i cares about its target utility relative to the benefits and costs of emissions. We assume the following functional forms:

$$\begin{aligned} b_i(x_i) &= x_i^{\alpha_i} && (2)\\ p_i(x_1,...,x_n) &= x_i^{\alpha_i}\left(x_i + \sum\nolimits_{j\neq i} x_j\right) && (3)\\ t_i\left(x_i, b_i^R\right) &= \begin{cases} \left(b_i(x_i) - b_i^R\right), \text{ if } b_i(.) \geq b_i^R \\ \lambda_i\left(b_i(x_i) - b_i^R\right), \text{ otherwise} \end{cases}. && (4)\end{aligned}$$

A higher value of the country i's exogenously determined technological inefficiency $\alpha_i \in (0,1)$ requires higher emissions to reach a given economic benefit. We call country i "developing" if it is technologically inefficient (relatively high α_i), and "developed" if it is technologically efficient (relatively low α_i). We use $\alpha \equiv (\alpha_1,...,\alpha_n)$ to denote the vector of countries' technological inefficiency parameters and normalize

[9] For convenience, we use the word "country" to refer to both a country and its political leader.

them, $\sum_{j=1}^{n} \alpha_j = 1$.

Note that the economic benefit function $b_i(x_i)$ is strictly increasing, concave, and $b_i(0) = 0$. The cost of pollution $p_i(x_1, ..., x_n)$ is strictly increasing in all terms, $p_i(0, ..., 0) = 0$, and has the following two properties: (i) $\frac{\partial p_i}{\partial x_j} < \frac{\partial p_i}{\partial x_i}$ for $j \neq i$, and (ii) $p_i(x_1, ..., x_n) > p_j(x_1, ..., x_n)$ if $\alpha_i < \alpha_j$. Property (i) implies that a marginal increase in domestic emissions is more damaging than the same marginal increase in another country. This means that either the emission has additional local effects beside the global effects, or in addition to the real effects, it has psychological effects, such as people feeling guilty about their own country's emissions. Property (ii) implies that, regardless of sources, people in developed countries are more environmentally aware and perceive more of environmental damage than people do in developing countries.[10]

The target utility $t_i\left(x_i, b_i^R\right)$ captures a country being averse to losing its economic benefits relative to its economic target b_i^R. We can consider this to be country i's economic reference level. In other words, if the economic benefit reaches this *level*, $b_i(.) \geq b_i^R$, then the country is satisfied by the positive difference, which it perceives as a gain. On the other hand, if the economic benefit does not reach the target, $b_i(.) < b_i^R$, then the country is disappointed by this negative difference, which it perceives it as a loss. Moreover, countries tend to strongly prefer avoiding economic losses to acquiring gains, relative to the economic target. The loss-aversion parameter $\lambda_i > 1$ measures how country i values losses versus gains. The function $t_i(.)$ is increasing in its emission level, decreasing in its economic target, and independent of how much other countries emit.

The net-benefit function of country i with an economic target simplifies to the following:

$$B_i\left(x_1, ..., x_n, \Lambda_i, b_i^R\right) = \begin{cases} x_i^{\alpha_i}\left(1 + \gamma_i - x_i - \sum_{j \neq i} x_j\right) - \gamma_i b_i^R, \text{ if } b_i^G(.) \geq b_i^R \\ x_i^{\alpha_i}\left(1 + \Lambda_i - x_i - \sum_{j \neq i} x_j\right) - \Lambda_i b_i^R \text{ , otherwise} \end{cases}, \tag{5}$$

where $\Lambda_i = \gamma_i \lambda_i < 1$ captures the economic target concerns of country i in the loss domain. Country i, with an economic target, initially maximizes the objective function in the first row, $B_i^G(.)$. If the economic benefit reaches the target, $b_i^G(.) \geq b_i^R$, then country i is in the gain domain and its net benefit is determined. However, if the economic benefit does not reach its target, $b_i^G(.) \leq b_i^R$, then country i is in the loss domain and maximizes the objective function in the second row, $B_i^L(.)$.[11] For a *standard* country i, there is no target utility in (1).

Any country i belongs one of the three types $\theta_i \in \{L, G, S\}$: that fails to reach its economic target (L); that reaches its economic target (G); and with no economic target (S). We use $\theta \equiv (\theta_1, ..., \theta_n)$ to denote the vector of countries' types. In order to study the impact of different types of countries, we solve the model for the case in which all countries fail to reach their economic targets. The results for the other types of countries can be found by simply applying $\Lambda_i = \gamma_i$ for any country i reaching its economic target

[10] Neumayer (2002) shows that democracies exhibit stronger international environmental commitment than non-democracies. This supports property (ii) if one accepts that democracies are also more developed.

[11] For some parameter values, countries can fail to reach their economic target when maximizing $B_i^G(.)$ and then reach their economic target when maximizing $B_i^L(.)$. This maximization procedure is to eliminate potential loops.

(G), and $\Lambda_i = 0$ for any standard country i (S). Note that Λ_i increases as a country's type changes in the direction of $S \to G \to L$.

3 Static Game

The aim of this section is to characterize the non-cooperative Nash equilibrium of n technologically asymmetric countries with economic targets. The Nash equilibrium serves as a credible punishment or threat to support international environmental cooperation in the repeated setting examined in the following section.[12]

In the non-cooperative Nash solution, each country sets its emission level where the marginal benefit is equal to the marginal cost. We find the best response function BR_i and Nash emission for country i x_i^N using the standard first-order condition $\partial B_i^L(.)/\partial x_i = 0$, as well as some additional algebra:

$$\frac{\partial B_i^L(.)}{\partial x_i} = \alpha_i x_i^{\alpha_i - 1}\left(1 + \Lambda_i - x_i - \sum_{j \neq i} x_j\right) - x_i^{\alpha_i} = 0, \tag{6}$$

The first-order condition shows that economic target concerns Λ_i increases the marginal benefit of emissions. Multiplying the first-order condition by $x_i^{1-\alpha_i} > 0$ gives:

$$\alpha_i\left(1 + \Lambda_i - \sum_{j=1}^{n} x_j\right) - x_i = 0 \text{ for } i = 1, 2, ..., n, \tag{7}$$

and determines the best response function for country i:

$$BR_i(x_{-i}) = \frac{\alpha_i\left(1 + \Lambda_i - \sum_{j \neq i} x_j\right)}{1 + \alpha_i}, \tag{8}$$

where $x_{-i} \equiv (x_1, ..., x_{i-1}, x_{i+1}, ..., x_n)$. Note that country i's emission level when it best responds to other countries' emissions increases in its economic target concerns, i.e., higher Λ_i, and as it becomes technological less efficient, i.e., higher α_i. Summing n equations in (7) and solving for the total emission level gives:

$$\sum_{j=1}^{n} x_j^N = \frac{\sum_{j=1}^{n} \alpha_j + \sum_{j=1}^{n} \alpha_j \Lambda_j}{1 + \sum_{j=1}^{n} \alpha_j}, \tag{9}$$

where x_j^N is country j's Nash emission level. Substituting (9) into (7) and using $\sum_{j=1}^{n} \alpha_j = 1$ gives the Nash emission level below:

[12] The static Nash equilibrium would be the unique equilibrium for the dynamic game as well if an IEA were not feasible (e.g., owing to exogenous, political reasons, or because countries are impatient and do not value the future.)

$$x_i^N = \frac{\alpha_i}{2}\left(1 + \Lambda_i\left(2 - \alpha_i\right) - \sum_{j \neq i} \alpha_j \Lambda_j\right). \tag{10}$$

Equation (10) shows that stronger country i's economic target concern, that is, an increase in Λ_i, imply a higher Nash emission level for country i. In other words, Nash emission level of a country with an economic target places more value on the economic benefits than a standard type country does, and even more so if it is a type L than G. On the other hand, a higher Λ_j for any other country j implies a lower Nash emission level for country i. This is due to the environmental concern of country i about the higher environmental pollution caused by country j. Note also that country i's Nash emission level increases as the country becomes technologically less efficient, i.e., higher α_i, and as the other countries becomes technologically more efficient, i.e., lower α_j's.[13]

For any given types θ, the Nash emission levels are inefficiently high (i.e., $x_i^O < x_i^N$ for all i), where the optimum level of emissions $x^O \equiv \left(x_1^O, ..., x_n^O\right)$ maximizes the countries' joint net-benefits $\sum_{i=1}^{n} B_i$. This is because emissions are transboundary and the negative spillover effects are not internalized when the countries act non-cooperatively.[14]

4 Dynamic Game

In this section we study the repeated interaction between countries. More precisely, the static game analyzed in the previous section is repeated infinitely many times in the dynamic game, and countries discount the future period by a discount factor $\delta \in (0, 1)$. We focus on self-enforcing IEAs. Thus, countries cannot make binding commitments. In such a setting, countries can sustain international environmental cooperation, the degree of which depends on how severely they can credibly punish a deviator. Our aim in this section is to examine the consequences of economic targets and loss-aversion for the sustainability of a cooperative emission equilibrium in the framework of an IEA with full participation. Thus, our framework is in line with the U.N. Climate Summits, in which participation has been almost universal.

Countries employ infinite Nash reversion strategies to enforce environmental cooperation.[15] We focus on cooperative subgame-perfect equilibria in which the following hold: (i) along the equilibrium path, the countries implement cooperative emission levels in each period; and (ii) if at any point in the game a defection occurs, all countries revert to non-cooperative Nash emission levels from the following period onwards. Each country i will prefer to emit at the cooperative emission levels if its net benefit from

[13] See the appendix for calculations.

[14] Using the first order conditions, $\partial \sum_{i=1}^{n} B_i^L / \partial x_i = 0$, the optimum level of emissions under full symmetry becomes: $x_i^O = \frac{\alpha_i(1+\Lambda_i)}{n(1+\alpha_i)}$. There are no closed-form solutions for optimum emissions in the case of asymmetry. Nevertheless, they are not needed for the sustainability of IEAs.

[15] We employ infinite Nash reversion strategies for simplicity, but they have well-known credibility issues. Instead, we could consider other strategies, such allowing renegotiation (Barrett, 1994; Asheim and Holtsmark, 2009). In these cases, the degree of cooperation that any type of countries could sustain would be quantitatively different. Nevertheless, all the forces leading to the qualitative results would remain the same.

cooperating is no less than its payoff from defection. The latter payoff consists of a one-period gain from deviation and the discounted net benefit of playing Nash reversion forever; that is:

$$\frac{1}{1-\delta}B_i\left(x^C,\Lambda,\alpha,b_i^R\right) \geq B_i\left(BR_i\left(x_{-i}^C\right),x_{-i}^C,\Lambda,\alpha,b_i^R\right)+\frac{\delta}{1-\delta}B_i\left(x^N,\Lambda,\alpha,b_i^R\right), \tag{11}$$

where $\Lambda \equiv (\Lambda_1,...,\Lambda_n)$ is the vector of economic target concerns, indicating also the country types θ, $x^C \equiv \left(x_1^C,...,x_n^C\right)$ is the vector of cooperative emission levels, and $BR_i\left(x_{-i}^C\right)$ is the best response function of country i when other countries emit at the agreed cooperative emission levels. From Friedman (1971), we know that for a sufficiently high discount factor δ and any given economic target concerns Λ, there is a subgame-perfect Nash equilibrium at a vector of cooperative emission levels x^C, such that $x_i^C \in \left[\overline{x}_i^C, x_i^N\right)$, where $\overline{x}_i^C$ is the most cooperative emission level country i can sustain.

Substituting cooperative emissions x^C, the best response function in (8), and Nash emission in (10) into $B_i^L\left(.\right)$ give the net benefit functions when all countries cooperate, when country i unilaterally deviates while others continue to cooperate, and at the Nash emissions, respectively: [16]

$$B_i^L\left(x^C,\Lambda,\alpha,b_i^R\right)=\left(x_i^C\right)^{\alpha_i}\left(1+\Lambda_i-x_i^C-\sum\nolimits_{j\neq i}x_j^C\right)-\Lambda_i b_i^R, \tag{12}$$

$$B_i^L\left(BR_i\left(x_{-i}^C\right),x_{-i}^C,\Lambda,\alpha,b_i^R\right)=\frac{1}{\alpha_i}\left(\frac{\alpha_i}{1+\alpha_i}\left(1+\Lambda_i-\sum\nolimits_{j\neq i}x_j^C\right)\right)^{1+\alpha_i}-\Lambda_i b_i^R, \tag{13}$$

$$B_i^L\left(x_1^{NL},...,x_n^{NL},\Lambda,\alpha,b_i^R\right)=\alpha_i^{\alpha_i}\left(\frac{1+\Lambda_i\left(2-\alpha_i\right)-\sum\limits_{j\neq i}\alpha_j\Lambda_j}{2}\right)^{1+\alpha_i}-\Lambda_i b_i^R. \tag{14}$$

Similar to public goods game, we have $B_i\left(BR_i\left(x_{-i}^C\right),x_{-i}^C,\Lambda,\alpha,b_i^R\right) > B_i\left(x^C,\Lambda,\alpha,b_i^R\right) > B_i\left(x^N,\Lambda,\alpha,b_i^R\right)$. We take the terms on the RHS over to the LHS in (11) and call this country i's sustainability function $S_i\left(x^C,\Lambda,\alpha,\delta\right)$. Substituting (12), (13), and (14) into (11) give the sustainability function, $S_i\left(.\right)=$

$$\frac{\left(x_i^C\right)^{\alpha_i}}{1-\delta}\left(1+\Lambda_i-x_i^C-\sum\nolimits_{j\neq i}x_j^C\right)-\frac{\left(\frac{\alpha_i\left(1+\Lambda_i-\sum_{j\neq i}x_j^C\right)}{1+\alpha_i}\right)^{1+\alpha_i}}{\alpha_i}-\frac{\delta\alpha_i^{\alpha_i}}{1-\delta}\left(\frac{1+\Lambda_i\left(2-\alpha_i\right)-\sum\limits_{j\neq i}\alpha_j\Lambda_j}{2}\right)^{1+\alpha_i}. \tag{15}$$

Given the parameters of the model, the sustainability function gives non-negative values for sustainable cooperative emission levels, and gives negative values for unsustainable cooperative emission levels. In this paper, our main concern is how the economic target concerns affect the sustainability of an agreed cooperative emissions. An increase in country i's economics target concerns Λ_i does only increase the impact of the target utility. It means that the impact of this increase depends on the levels of the economic benefit $b_i\left(.\right)$ and the economic target b_i^R. Note that the economic target parameters in $S_i\left(.\right)$ cancel each other out $\left(\Lambda_i b_i^R\left(\frac{1}{1-\delta}-1-\frac{\delta}{1-\delta}\right)=0\right)$. Thus, the country's economic target only determines its type, but has no other effect on sustainability. Therefore, given the types, the impact of an increase in economic

[16] More detailed calculations are provided in the appendix.

target concerns on sustainability depends on the economic benefit levels when country i cooperates $b_i^C \equiv b_i\left(x_i^C\right)$, when it unilaterally deviates while others continue to cooperate $b_i^D \equiv b_i\left(BR_i\left(x_{-i}^C\right)\right)$, and at the Nash emissions $b_i^N \equiv b_i\left(x_i^N\right)$.

Our first proposition describes the impact on sustaining a cooperative emission level if country i is more concerned about its economic target. This increase in economic target concerns can be due country i's type changing in the direction of $S \to G \to L$.

Proposition 1 *Given any cooperative emission levels x^C, technological inefficiencies with $\sum_{j=1}^{n} \alpha_j = 1$, economic target concerns Λ, and a common discount factor δ, if country i is more concerned about its economic target, i.e., higher Λ_i, then*

(i) it is more difficult to sustain cooperation at the agreed cooperative emission x^C for country i, i.e., $\partial S_i/\partial\Lambda_i < 0$, and

(ii) it is easier for any country j to sustain cooperation at x^C, i.e., $\partial S_j/\partial\Lambda_i > 0$.

An increase in country i's economic target concerns increases its marginal benefit from emission. Since $x_i^C < x_i^N < BR_i(x_{-i}^C)$ for any θ, the economic benefits at these emission levels are ordered as follows: $b_i^C < b_i^N < b_i^D$. Furthermore, while country i's cooperative emission level does not change, its Nash emission level and emission level when it unilaterally deviates from the cooperative emission level increases in Λ_i. These imply a stronger incentive to deviate and, thus, a decrease in $S_i\left(.\right)$. Sustaining cooperation at x^C becomes more difficult for country i. On the other hand, an increase in Λ_i for any other country j only decreases country j's Nash emission level because of the strategic substitutability of countries' emission levels, thus lowering its incentive to deviate from the agreed cooperative emissions. Therefore, sustaining cooperation at x^C becomes easier for country j.

Next, we discuss the impact on sustaining a cooperative emission level if all countries are more concerned about their economic targets. To this end, we increase the economic target concerns uniformly, while still allowing these concerns to be different from each other.

Proposition 2 *Given any cooperative emission levels x^C, technological inefficiencies with $\sum_{j=1}^{n} \alpha_j = 1$, economic target concerns Λ, and a common discount factor δ, an equal increase in all countries economic target concerns, $d\Lambda_i = d\Lambda_j \; \forall ij$, impedes country i sustaining cooperation at x^C if $dS_i = \frac{\partial S_i}{\partial \Lambda_i} d\Lambda_i + \sum_{j \neq i} \frac{\partial S_i}{\partial \Lambda_j} d\Lambda_j < 0 \Leftrightarrow$*

$$b_i^C - (1-\delta)\, b_i^D + \frac{1}{2}\left(1+\alpha_i\right)\delta\left(n - 3 - \alpha_i\left(n-2\right)\right) b_i^N < 0. \tag{16}$$

(i) If $\alpha_i \leq \frac{n-3}{n-2}$, which requires $n \geq 4$, then b_i^N enters non-negatively and the inequality (16) does not hold for sufficiently large δ. Otherwise, b_i^N enters negatively and the inequality (16) or the opposite can hold.

(ii) It is easier for the inequality (16) to hold for a lower x_i^C and higher x_j^C's.

While Proposition 1 examines the impact of one country being more concerned about its economic targets, Proposition 2 examines the impact of all countries having stronger concerns about their economic targets. Thus, for each of n countries, there are two effects, as discussed in Proposition 1: (i) an increase in Λ_i hinders sustaining cooperation for country i, but (ii) facilitates cooperation for any other country j. If the inequality (16) holds, Proposition 1's (i) dominates (ii) when all countries have stronger economic target concerns. If the opposite of inequality (16) holds strictly, then (ii) dominates (i).

The first point in Proposition 2 states that if there are sufficiently many and patient countries, (ii) dominates (i) for a technologically not very inefficient country i. If any of these conditions fail to hold, then depending on the specific parameter values (i) or (ii) dominates the other. To gain more insight into this, first note that the number of countries and countries' technological inefficiencies are linked due to the normalization, $\sum_{j=1}^{n} \alpha_j = 1$. An increase in the number of countries requires at least some countries to become technologically more efficient. For any given number of countries, a country i being sufficiently technologically efficient and, thus sufficiently environmentally aware, imply the other countries to be sufficiently technologically inefficient and environmentally unaware. For such a developed country i, the effect (ii) would become stronger, since increase in Nash emission levels owing to the increase in economic target concerns would be smaller; and, the effect (i) would be weaker, since increase in Nash emission levels and emission levels when country i unilaterally deviates from the cooperative emission level owing to the increase in economic target concerns would be smaller. Note that if (i) dominates (ii) for some countries and they cannot sustain cooperation at x^C anymore, then IEA would breaks down.

note that for countries to continue sustaining cooperation at the agreed cooperative emission levels anymore, then that

The second point in Proposition 2 states that if country i agrees on a more cooperative emission level $\overline{x}_i^C$ or some other countries j's agree on a less cooperative emission levels $\overline{x}_j^C$'s, then it is easier for the inequality (16) to hold. The intuition is straightforward: a more cooperative (lower) emission level $\overline{x}_i^C$ would reduce country i's economic benefit at cooperative emission level and a less cooperative emission levels $\overline{x}_j^C$'s would increase country i's economic benefit when it unilaterally deviates from the cooperative emissions.

4.1 Sustainability, the Critical Discount Factor, and the Most Cooperative Emissions

In all the propositions, we study how changes in economic target concerns, either country i's or any other country j's or all countries, affect the sustainability a cooperative emission level, given the agreed upon cooperative emission levels x^C and a common discount factor δ. Alternatively, we could study the impact of economic target concerns on the critical discount factor above which x^C can be sustained by country i or on the most cooperative (minimum) cooperative emission levels $\overline{x}^C$ for a given δ. To this end, first we solve the no-defection condition (11) for δ and obtain the critical discount factor above which x^C can be sustained by country i:[17]

$$\delta \geq \underline{\delta}_i(x^C, \Lambda, \alpha) = \frac{B_i^D - B_i^C}{B_i^D - B_i^N}, \tag{17}$$

[17] See the appendix for more detailed calculations.

where B_i^C, B_i^D, and B_i^N are abbreviations of the net benefit function when all countries cooperate, when country i unilaterally deviates while others continue to cooperate, and at the Nash emissions, respectively. At its critical discount factor $\underline{\delta}_i(x^C, \Lambda, \alpha)$, country i can just sustain the agreed cooperative emissions x^C, thus, its sustainability function equals to zero, $S_i\left(x^C, \Lambda, \alpha, \underline{\delta}_i\right) = 0$.

So far, we have studied how changes in economic target concerns affect countries sustaining cooperation at a x^C. Next, we study the relationship between country i's ability to sustain cooperation at a x^C and its critical discount factor. This allows us to interpret our previous results from the perspective of countries' patience levels.

Lemma 1 *Given any cooperative emission levels x^C, technological inefficiencies with $\sum_{j=1}^{n} \alpha_j = 1$, economic target concerns Λ, if country i's ability to sustain cooperation at x^C increases (decreases) for some reason other than discount factor δ and cooperative emission levels x^C, $S_i'(x^C, \delta_i) > (<) S_i(x^C, \delta_i)$, then the critical (minimum) discount factor above which x^C can be sustained by country i decreases (increases), $\underline{\delta'}_i(x^C) < (>) \underline{\delta}_i(x^C)$.*

If country i's ability to sustain cooperation at x^C has increased for whatever reason other than δ_i and x^C, then the critical discount factor before the increase does not bind for sustaining cooperation at x^C. This means that country i can sustain agreed cooperative emission x^C with some discount factors lower than the critical discount factor before the increase. Thus, the critical discount factor decreases after the increase in country i's ability to sustain cooperation at x^C. A decrease in critical discount factor $\underline{\delta}_i(x^C)$ means even some other relatively impatient country i's can start sustaining cooperation at x^C. Similarly, a decrease in country i's ability to sustain cooperation at x^C requires $\underline{\delta}_i(.)$ to increase and, thus, only sufficiently patient country i's can continue sustaining cooperation at x^C.

Next, we study the relationship between country i's ability to sustain cooperation at x^C and the most cooperative emission level it can sustain. This allows us to interpret our previous results from the perspective of lowest emissions countries can sustain.

Proposition 3 *Given any technological inefficiencies with $\sum_{j=1}^{n} \alpha_j = 1$, economic target concerns Λ, and a sufficiently high discount factor δ_i of country i,*

(i) If country i's ability to sustain cooperation at x^C increases (decreases) for some reason other than discount factor δ_i and cooperative emission levels x^C, i.e., $S_i'(x^C, \delta_i) > (<) S_i(x^C, \delta_i)$, then country i's most cooperative emission decreases (increases), $\overline{x}_i'^C < (>) \overline{x}_i^C$.

(ii) If all countries' abilities to sustain cooperation at x^C increase (decrease) for some reason other than discount factor δ_i and cooperative emission levels, x^C, i.e., $S_i'(x^C, \delta_i) > (<) S_i(x^C, \delta_i)$ for all i, then the most cooperative emission levels countries can sustain decrease (increase), $\overline{x}'^C < (>) \overline{x}^C$ in all dimensions.

The intuition behind the Proposition 3 is similar to the one underlying Lemma 1. Basically, after any country's ability to sustain cooperation at x^C increases for whatever reason other than its discount factor and cooperative emission, the critical discount factor before the increase does not bind for sustaining cooperation at x^C. This means that countries with higher ability to sustain cooperation at x^C can support greater degree of international environmental cooperation.

An interesting point is that a country j's ability to sustain cooperation at x^C increases as x_i^C decreases if $b_j^C > b_j^D(1-\delta)$.[18] This means that country i becoming more cooperative in its emission level allows some sufficiently patient countries to also emit more cooperatively.

5 Extensions

5.1 Symmetric Countries

In this subsection, we assume countries to be symmetric. More specifically, we assume countries to be identical in their technological inefficiencies, $\alpha_i = 1/n$ for any i, economic target concerns, $\Lambda_i = \Lambda_j$, and agreed cooperative emission levels, $x_i^C = x_j^C \,\forall\, ij$. As in proposition 2, we study the impact of all countries being more concerned about their economic targets.

Proposition 4 *Given technological inefficiencies $\alpha_i = 1/n$ for any i, a common discount factor δ, and identical economic target concerns $\Lambda_i = \Lambda_j \,\forall ij$, the most cooperative emission level country i can sustain $\overline{x}_i^C$ increases in economic target concerns if i.e., $\partial S_i / \partial \Lambda_i < 0 \Leftrightarrow$*

$$b_i^C < (1-\delta)\, b_i^D + \frac{\delta}{2}\left(\frac{n+1}{n}\right) b_i^N. \tag{18}$$

Basically, the condition (16) simplifies to the condition (18) under symmetry. To investigate further this scenario, we also resort a numerical analysis. We assume that there are two countries i and j, identical in their technological inefficiencies $\alpha_i = \alpha_j = 1/2$, in their types $\theta_i = \theta_j$, in their discount factor $\delta_i = \delta_j = 0.99$, and agree to cooperate by emitting the same amount $x_i^C = x_j^C$. Moreover, we assume that economic target concerns are $\Lambda_i^L = \Lambda_j^L = 0.3$ for loss, $\Lambda_i^G = \Lambda_j^G = 0.15$ for gain, and $\Lambda_i^S = \Lambda_i^S = 0$ for standard types. We summarize the findings in Figure 1. It shows how sustainability functions changes against emissions with any country i's type $\theta_i \in \{L, G, S\}$. The red dotted, blue dashed, and continuous black curves represent countries being loss (L), gain (G), and standard (S) types, respectively. Each curve intersect the zero value line twice: the smaller emission level is the most cooperative emission level countries can sustain and the higher emission level is the Nash emission level.

For sufficiently high δ, we find that for some relatively high (less) cooperative emission levels the condition (18) does not hold, meaning that a joint increase in economic target concerns can increase the sustainability for such relatively high (less) cooperative emissions. On the other hand, if the countries agree on a low (more) cooperative emission level, then a joint increase in economic target concerns decreases the sustainability functions and, thus, the most cooperative emission levels of loss, gain, and standard types of countries are ordered as follows: $\overline{x}_i^{CL} > \overline{x}_i^{CG} > \overline{x}_i^{CS}$, for any i. Therefore, economic

[18] See the appendix for detailed calculations.

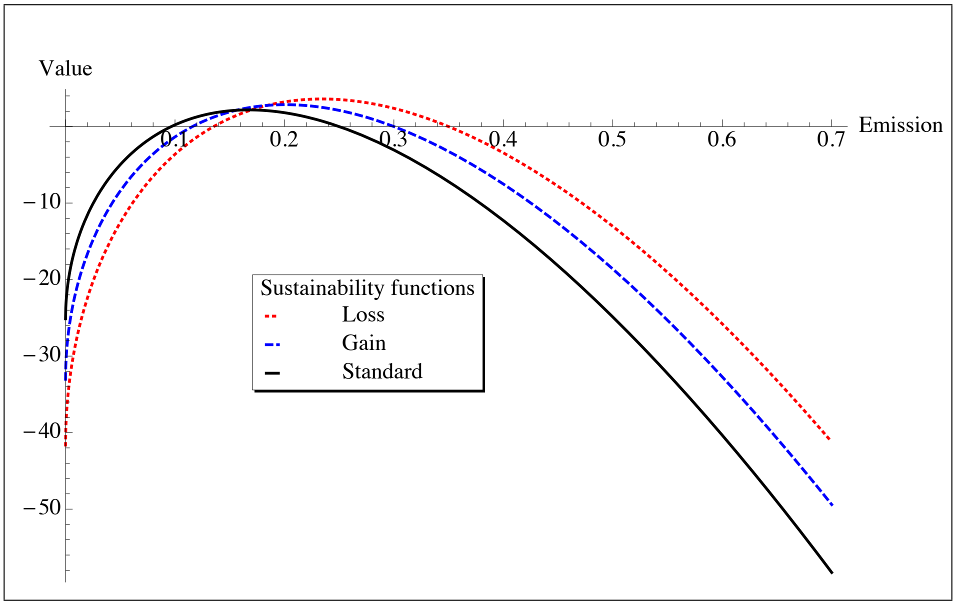


Figure 1: The most cooperative emissions

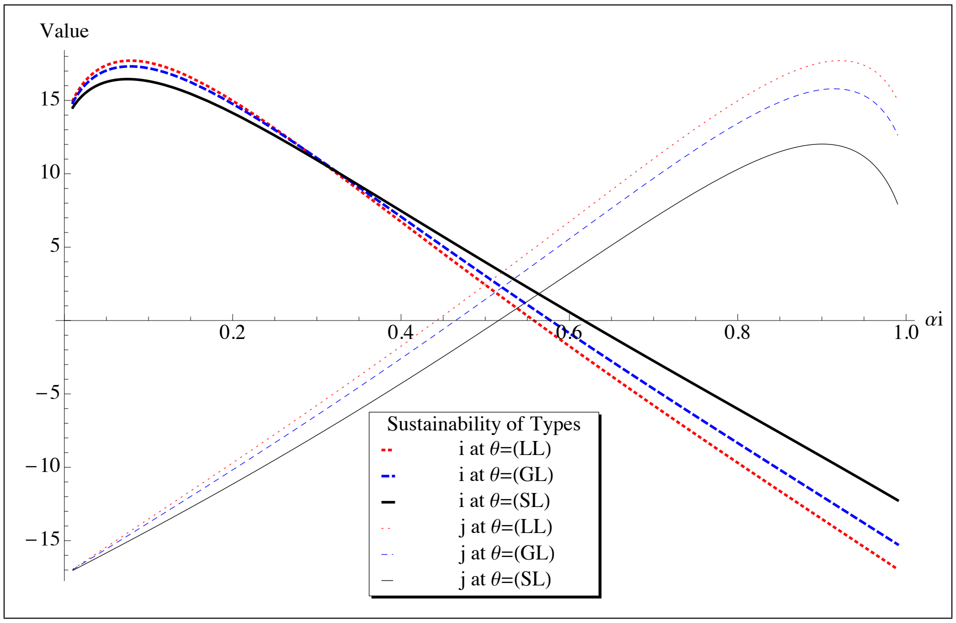
target concerns could be another reason preventing countries to support a greater degree of international environmental agreements.

5.2 Asymmetry in Technology

Next, we examine the impact of countries becoming more or less asymmetric in their technologies, in addition to their possibly asymmetric economic target concerns. This analysis allows us to study a North–South relations model as well as a North–North model. To this end, we employ a numerical analysis with two countries to incorporate how technological inefficiencies α_i and α_j, with $\alpha_i + \alpha_j = 1$, and different types $\theta = (\theta_i, \theta_j)$ affect countries' ability to sustain cooperation. Figure 2 contains two subfigures. Each shows how the sustainability of a symmetric cooperative emission, set to $x^C = (0.22, 0.22)$ here, against country i's technological inefficiency α_i changes with country i's type $\theta_i \in \{L, G, S\}$. The two subfigures differ by the other country j's type $\theta_j \in \{L, S\}$. Bold sustainability functions belong to country i and light sustainability functions belong country j. The red dotted, blue dashed, and continuous black curves represent country i being in a loss (L), gain (G), and standard (S) domain, respectively.

In both subfigures, the symmetry in technologies helps to sustain cooperation. The developing country fails to sustain cooperation if countries are sufficiently asymmetric in their technologies. For instance, in Subfigure 2a, where $\theta_j = L$, cooperation can be sustained by both countries at approximately $\alpha_i \in (0.52; 0.62)$, $\alpha_i \in (0.46; 0.58)$, and $\alpha_i \in (0.44; 0.56)$ for $\theta_i = S$, G, and L, respectively. Country i can sustain cooperation for values of α_i below the upper limit and country j can do so for values of α_i above the lower limit. As Λ_i increases, in other words, as the country i's type changes in the direction of $S \to G \to L$, the upper limit decreases, and sustaining cooperation becomes more difficult for country i. At the same time, the lower limit increases, making it easier for country j to sustain cooperation, as shown in Proposition 1.

(a) Type $\theta_i \in (L, G, S)$ and type $\theta_j = L$



(b) Type $\theta_i \in (L, G, S)$ and type $\theta_j = S$

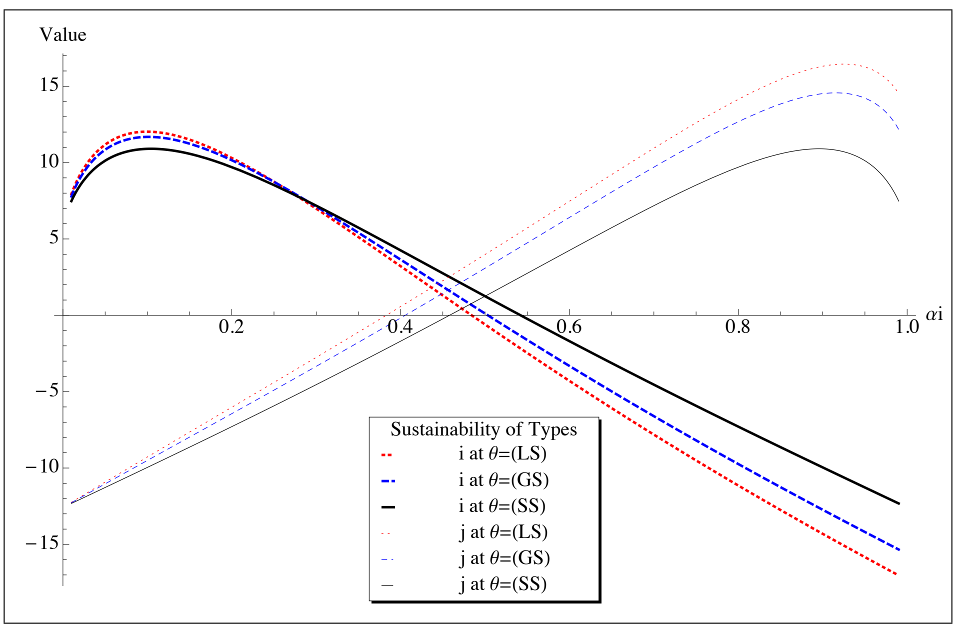


Figure 2: The net benefit of sustaining cooperation at $x^C = (0.22, 0.22)$ for country type pair $\theta = (\theta_i, \theta_j)$, when the loss-aversion parameter $\lambda_i = 1.5$ and the scaling factor $\gamma_i = 0.1$, for all i, and technological inefficiency α_i, when $\alpha_i + \alpha_j = 1$, at discount factor $\delta = 0.99$. Countries sustain cooperation for non-negative values. Bold sustainability functions represent country i and light sustainability functions represent country j. The red dotted, blue dashed, and continuous black lines represent country i's type being L, G, and S, respectively.

In the case of technological asymmetries, an increase in economic target concerns might help or hinder sustaining a cooperative emission. Figure 2 shows that the more developed country can sustain cooperation at the agreed upon emission level regardless of the economic target concerns. However, economic target concerns do matter for the sustainability of the less developed country. if country i is less developed (i.e., α_i's > 0.5), regardless of economic target concerns of the other country j, having stronger economic target concerns hinders its ability to sustain cooperation at the agreed upon emission level. On the other hand, the more developed county j having stronger economic target concerns facilitate sustaining cooperation for the less developed country i. Thus, the best scenario for the countries to sustain cooperation is the developing country i has weaker and the developed country j has stronger economic target concerns. However, if one considers that developed countries have more established political and economic institutions and would have weaker economic target concerns than developing countries, then economic target concerns enter as another difficulty for supporting substantial international environmental cooperation.

5.3 Comparative analysis with Economic Targets

In all our propositions, we focus on the impact of countries being more concerned about their economic targets Λ. Alternatively, we could examine the impact of countries having more ambitious economic targets b^R. This may lead to two possible scenarios. First, if a country continues to be in a gain or loss after an increase in its economic target b_i^R, then its objective function does not change. In this case, its emission level and sustainability functions remain the same. Second, if a country starts failing to reach its economic benefit after an increase in its economic target, then it will start maximizing $B_i^L(.)$. In this case, it will have stronger concerns about its economic targets. Therefore, the second scenario leads to identical implications discussed in the propositions.

6 Conclusion

Motivated by the fact that many policy decisions are often influenced by political parties' incentives to be elected, we examine the implications for IEAs on transboundary emissions of countries being motivated to reach their economic targets and being averse to failing to achieve their economic targets. More specifically, we examine whether countries having stronger economic target concerns help or hinder the sustainability of agreed upon cooperative emissions in the context of self-enforcing IEAs, that is, involving full participation.

We find that the stronger the concern of a country about its economic targets, the more difficult it is for the country to sustain cooperation, but the easier it is for other countries to do so. If all countries have stronger economic target concerns and are sufficiently patient, then it can facilitate sustaining cooperation for a sufficiently developed countries in the presence of developing countries, but the effect it ambiguous for a developing country. If the countries are symmetric in all dimensions, then countries having stronger economic target concerns hinders sustaining cooperation. This means that countries needs to be much more patient to continue sustaining the agreed cooperative emission levels or the most cooperative emission levels countries can sustain increase for the same patience level.

The real IEAs, such as climate change, are much more complex than the simple model utilized here. They require international coordination to agree on the cooperative emission levels, in which countries often fail to keep their promises. We show that even in a world in which sustaining the most cooperative emissions is effortless, ambitious economic targets owing to an incentive to be elected lead to IEAs with less cooperative emission levels than could be achieved without such concerns.

Thaler and Sunstein (2008), in their highly influential book, suggest nudges. It is a design of a choice environment using frames and defaults, among others, that alters people's behavior in a predictable way, without mandating a particular action or changing economic incentives, in order to overcome behavioral failures. However, the impact of nudges is limited if policymakers suffer from such behavioral failures, either directly or through voters, as discussed in the introduction. While a political party can frame the climate change problem to alter behavior to promote greener policies (e.g., Al Gore), another can frame it to favor inaction (e.g., the Bush administration).[19]

It appears that correcting the incentives leading to ambitious economic targets and an aversion to economic losses require a strong call for action at the sub-national level. As citizens of the earth, we should talk more about the environmental problems and raise public awareness to incentivize political parties to pursue greener policies.[20]

Appendix: Calculations and Proofs

Calculations:

Technological inefficiency and Nash emissions:

$$\begin{aligned}\frac{\partial x_i^N}{\partial \alpha_i} &= \frac{1}{2}\left(1+\Lambda_i\left(2-\alpha_i\right)-\sum_{j\neq i}\alpha_j\Lambda_j\right)-\frac{\alpha_i}{2}\Lambda_i \\ &= \frac{1}{2}\left(1+2\Lambda_i\left(1-\alpha_i\right)-\sum_{j\neq i}\alpha_j\Lambda_j\right)>0\end{aligned} \tag{19}$$

It is straightforward to see $\partial x_i^N/\partial\alpha_j < 0$.

Net benefit functions:

It is straightforward to see that substituting cooperative emissions into $B_i^L(.)$ gives (12). Let's substitute the best response function in (8) into $B_i^L(.)$ to find the net benefit function when country i unilater-

[19] See Gsottbauer and van den Bergh (2013) for the details of these frames.

[20] Communication and raising public awareness is one of the four strategic priorities of the U.N. Environmental Programme's climate change programme. http://www.unep.org/pdf/UNEP_CC_STRATEGY_web.pdf

ally deviates while others continue to cooperate, $B_i^L\left(BR_i\left(x_j^C\right), x_j^C, b_i^R\right) =$

$$\begin{aligned}
&= \left(\frac{\alpha_i}{1+\alpha_i}(1+\Lambda_i - \sum_{j\neq i} x_j^C)\right)^{\alpha_i} \left(1+\Lambda_i - \sum\nolimits_{j\neq i} x_j^C - \frac{\alpha_i}{1+\alpha_i}(1+\Lambda_i - \sum_{j\neq i} x_j^C)\right) - \Lambda_i b_i^R \\
&= \left(\frac{\alpha_i}{1+\alpha_i}(1+\Lambda_i - \sum_{j\neq i} x_j^C)\right)^{\alpha_i} \left(\frac{1}{1+\alpha_i}(1+\Lambda_i - \sum_{j\neq i} x_j^C)\right) - \Lambda_i b_i^R \\
&= \frac{1}{\alpha_i}\left(\frac{\alpha_i}{1+\alpha_i}\left(1+\Lambda_i - \sum\nolimits_{j\neq i} x_j^C\right)\right)^{1+\alpha_i} - \Lambda_i b_i^R
\end{aligned} \tag{20}$$

We substitute Nash emission in (10) into $B_i^L(.)$. Using the (9) and some algebra give the net benefit at the Nash emissions, $B_i^L\left(x_1^{NL}, ..., x_n^{NL}, b_i^R\right) =$

$$\begin{aligned}
&= \left(x_i^{NL}\right)^{\alpha_i}\left(1+\Lambda_i - \sum_{i=1}^{n} x_i^{NL}\right) - \Lambda_i b_i^R \\
&= \left(\frac{\alpha_i}{2}\left(1+\Lambda_i\left(2-\alpha_i\right) - \sum_{j\neq i}\alpha_j\Lambda_j\right)\right)^{\alpha_i}\left(1+\Lambda_i - \frac{1+\sum\limits_{j=1}^{n}\alpha_j\Lambda_j}{2}\right) - \Lambda_i b_i^R \\
&= \alpha_i^{\alpha_i}\left(\frac{1}{2}\left(1+\Lambda_i\left(2-\alpha_i\right) - \sum_{j\neq i}\alpha_j\Lambda_j\right)\right)^{\alpha_i}\frac{1}{2}\left(1+2\Lambda_i - \sum_{j=1}^{n}\alpha_j\Lambda_j\right) - \Lambda_i b_i^R \\
&= \alpha_i^{\alpha_i}\left(\frac{1}{2}\left(1+\Lambda_i\left(2-\alpha_i\right) - \sum_{j\neq i}\alpha_j\Lambda_j\right)\right)^{\alpha_i}\frac{1}{2}\left(1+\Lambda_i(2-\alpha_i) - \sum\nolimits_{j\neq i}\alpha_j\Lambda_j\right) - \Lambda_i b_i^R \\
&= \alpha_i^{\alpha_i}\left(\frac{1+\Lambda_i\left(2-\alpha_i\right) - \sum\limits_{j\neq i}\alpha_j\Lambda_j}{2}\right)^{1+\alpha_i} - \Lambda_i b_i^R
\end{aligned} \tag{21}$$

Critical Discount Factor

The conditions (11) and (17) are equivalent. For notational simplicity, let us use B_i^C, B_i^{BR}, and B_i^N for net benefit functions when all countries cooperate, when country i unilaterally deviates while others continue to cooperate, and at the Nash emissions, respectively.

$$\begin{aligned}
\frac{1}{1-\delta}B_i^C \geq B_i^{BR} + \frac{\delta}{1-\delta}B_i^N &\Leftrightarrow \\
B_i^C \geq (1-\delta)B_i^{BR} + \delta B_i^N &\Leftrightarrow \\
\delta\left(B_i^{BR} - B_i^N\right) \geq B_i^{BR} - B_i^C &\Leftrightarrow \\
\delta \geq \frac{B_i^{BR} - B_i^C}{B_i^{BR} - B_i^N}&
\end{aligned} \tag{22}$$

Interdependence of Countries' Most Cooperative Emissions

$$\begin{aligned}\frac{\partial S_j}{\partial x_i^C} &= -\frac{(x_j^C)^{\alpha_j}}{1-\delta} + \left(\frac{\alpha_j}{1+\alpha_j}\left(1+\Lambda_j - \sum\nolimits_{i\neq j} x_i^C\right)\right)^{\alpha_j} \Leftrightarrow \\ &= -\frac{b_j^C}{1-\delta} + b_j^D\end{aligned} \tag{23}$$

For $\frac{\partial S_j}{\partial x_i^C} < 0$, we should have: $b_j^C > b_j^D(1-\delta)$.

Proofs:

Proof of Proposition 1.

We take the derivative with respect to (i) $\Lambda_i = \gamma_i \lambda_i$:

$$\frac{\partial S_i}{\partial \Lambda_i} = \frac{1}{1-\delta}\underbrace{\left(x_i^C\right)^{\alpha_i}}_{b_i^C} - \underbrace{\left(\frac{1+\Lambda_i - \sum_{j\neq i} x_j^C}{1+\alpha_i}\right)^{\alpha_i}}_{b_i^{BR}} - (2-\alpha_i)(1+\alpha_i)\frac{\delta}{2(1-\delta)}\underbrace{\alpha_i^{\alpha_i}\left(\frac{1+(2-\alpha_i)\Lambda_i - \sum_{j\neq i}\alpha_j\Lambda_j}{2}\right)^{\alpha_i}}_{b_i^{NL}}. \tag{24}$$

For country i's sustainability to decrease in its economic target concerns, $\frac{\partial S_i}{\partial \Lambda_i} < 0 \Leftrightarrow$

$$b_i^C < \delta \underbrace{\frac{1}{2}(2-\alpha_i)(1+\alpha_i)}_{>1} b_i^{NL} + (1-\delta)\, b_i^{BR}. \tag{25}$$

Since $x_i^{NL} > x_i^C$ and $BR_i\left(x_{-i}^C\right) > x_i^C$, we have $b_i^{NL} > b_i^C$ and $b_i^{BR} > b_i^C$. Then, any point in convex combination of b_i^{NL} and b_i^{BR} is also higher than b_i^C, which completes part (i) of the proof.

Let us now take the derivative of S_j with respect to (ii) $\Lambda_i = \gamma_i \lambda_i$:

$$\frac{\partial S_j}{\partial \Lambda_i} = (1+\alpha_j)\frac{\delta}{1-\delta}\underbrace{\alpha_j^{\alpha_j}\left(\frac{1+(2-\alpha_j)\Lambda_j - \sum_{i\neq j}\alpha_i\Lambda_i}{2}\right)^{\alpha_j}}_{b_j^{NL}}\frac{\sum_{i\neq j}\alpha_i}{2} > 0 \tag{26}$$

This condition always holds because it is the same condition required for the Nash emissions to be positive in (10), completing the proof of part (ii). ■

Proof of Proposition 2. Total derivation of the sustainability function with respect to countries economic target concerns, $dS_i = \frac{\partial S_i}{\partial \Lambda_i}\, d\Lambda_i + \sum_{j\neq i}\frac{\partial S_i}{\partial \Lambda_j} d\Lambda_j$:

$$dS_i = \left(\frac{b_i^C}{1-\delta} - b_i^{BR} - \frac{(2-\alpha_i)(1+\alpha_i)\,\delta}{2(1-\delta)} b_i^{NL}\right) d\Lambda_i + \sum\nolimits_{j\neq i}\frac{(1+\alpha_i)\,\delta\sum_{j\neq i}\alpha_j}{2(1-\delta)} b_i^{NL} d\Lambda_j \tag{27}$$

Note that $\sum_{j\neq i}\alpha_j = 1-\alpha_i$. The sustainability of country i increases by an equal increase in all countries economic target concerns ($d\Lambda_i = d\Lambda\ \forall i$) if $dS_i > 0 \Leftrightarrow$

$$\begin{aligned} b_i^C - (1-\delta)\, b_i^{BR} - \frac{(2-\alpha_i)(1+\alpha_i)\,\delta}{2} b_i^{NL} + (n-1)\,\frac{(1+\alpha_i)\,\delta\,(1-\alpha_i)}{2} b_i^{NL} > 0 \Leftrightarrow \\ b_i^C - (1-\delta)\, b_i^{BR} + \frac{(1+\alpha_i)\,\delta}{2} b_i^{NL} \left((n-1)(1-\alpha_i) - 2 + \alpha_i\right) > 0 \Leftrightarrow \\ b_i^C - (1-\delta)\, b_i^{BR} + \frac{(1+\alpha_i)\,\delta}{2} b_i^{NL} \left(n - 3 - \alpha_i\,(n-2)\right) > 0 \end{aligned} \tag{28}$$

(i) The last parenthesis becomes positive if $\alpha_i \leq \frac{n-3}{n-2}$, which also requires $n \geq 4$. In this case, the condition (16) does not hold for sufficiently large δ. Otherwise, we need to know specific parameter values in order to determine whether the condition (16) holds or not.

(ii) It is easier for the condition (16) to hold for a lower x_i^C, since the only term that depends on it in the condition (16) is b_i^C, which decreases for a lower x_i^C. On the other hand, It is easier for the condition (16) to hold for higher x_j^C's, since the only term that depends on them in the condition (16) is b_i^D, which increases for higher x_j^C's.

■

Proof of Lemma 1. Given the parameters of the model, let $\underline{\delta}_i(x^C)$ be the critical discount factor so that $S_i(x^C, \underline{\delta}_i) = 0$. Suppose, for some reason other than discount factor δ_i and cooperative emissions x^C, country i's sustainability increases, $S_i'(x^C, \underline{\delta}_i) > S_i(x^C, \underline{\delta}_i) = 0$. Therefore, there exists another $\underline{\delta'}_i$ such that $S_i'(x^C, \underline{\delta'}_i) = 0$ and $\underline{\delta'}_i(.) < \underline{\delta}_i(.)$. ■

Proof of Proposition 3.

(i) Suppose country i's sustainability increases for some reason other than its discount factor δ_i and cooperative emissions x^C. We know by lemma 1 that if $S_i'(x^C, \delta_i) > S_i(x^C, \delta_i)$ for any cooperative emissions x^C, then $\underline{\delta'}_i(x^C) < \underline{\delta}_i(x^C)$. Furthermore, from (17), we have

$$\begin{aligned} B_i^D - B_i^C = \underline{\delta}_i(\overline{x}^C)\left(B_i^D - B_i^N\right) \\ B_i'^D - B_i'^C = \underline{\delta'}_i(\overline{x}^C)\left(B_i'^D - B_i'^N\right) \end{aligned} \tag{29}$$

Since $\underline{\delta'}_i(\overline{x}^C) < \underline{\delta}_i(\overline{x}^C)$:

$$\begin{aligned} B_i'^D - B_i'^C < \underline{\delta}_i(\overline{x}^C)\left(B_i'^D - B_i'^N\right) \Leftrightarrow \\ \left(1 - \underline{\delta}_i(\overline{x}^C)\right) B_i'^D < B_i'^C - \underline{\delta}_i(\overline{x}^C) B_i'^N, \end{aligned} \tag{30}$$

meaning that the no-defection condition (17) does not bind for country i at the $\left(\overline{x}^C, \underline{\delta}_i(\overline{x}^C)\right)$ pair. Note that B_i^N does not depend on the cooperative emissions. Moreover, B_i^D does not depend on country i's cooperative emissions. Thus, country i can sustain cooperation at $\hat{x}^C$ such that $\hat{x}_i^C < \overline{x}_i^C$ and $\hat{x}_j^C = \overline{x}_j^C$ for any j. Since these arguments apply to any $\left(\overline{x}_i^C, \underline{\delta}_i(\overline{x}^C)\right)$ pair for any $\underline{\delta}_i(\overline{x}^C)$ that countries can maintain some cooperation, we have that for any such δ, $\overline{x}_i'^C < \overline{x}_i^C$.

(ii) Let all countries' sustainability functions increases for some reason other than its discount factors and cooperative emissions. For any country i, the condition (30) does hold. For any cooperative emissions

x^C lower than $\overline{x}^C$ in all dimensions, net benefit under defection is higher at x^C than at $\overline{x}^C$:

$$B_i\left(BR_i\left(x_{-i}^C\right), x_{-i}^C, \Lambda, b_i^R\right) > B_i\left(BR_i\left(\overline{x}_{-i}^C\right), \overline{x}_{-i}^C, \Lambda, b_i^R\right) \tag{31}$$

Furthermore, for such a $x^C < \overline{x}^C$, net benefit under cooperation is also higher at x^C than at $\overline{x}^C$:

$$B_i\left(x^C, \Lambda, \alpha, b_i^R\right) > B_i\left(\overline{x}^C, \Lambda, \alpha, b_i^R\right) \tag{32}$$

By the continuity of $B_i\left(.\right)$, there exist a cooperative emissions vector $\tilde{x}^C < \overline{x}^C$ such that for any country i the condition (30) still holds. Since these arguments apply to any $\left(\overline{x}_i^C, \underline{\delta}_i(\overline{x}^C)\right)$ pair for any $\underline{\delta}_i(\overline{x}^C)$ that countries can maintain some cooperation, we have that for any such δ, $\overline{x}'^C < \overline{x}^C$. ■

Proof of Proposition 4.

Country i's sustainability function under symmetry:

$$S_i^= = \frac{\left(x^C\right)^{1/n}}{1-\delta}\left(1+\Lambda_i - nx_i^C\right) - n\left(\frac{1}{n+1}\left(1+\Lambda_i-(n-1)x_i^C\right)\right)^{\frac{n+1}{n}} - \frac{\delta(1/n)^{1/n}}{1-\delta}\left(\frac{1+\Lambda_i}{2}\right)^{\frac{n+1}{n}}. \tag{33}$$

We take the derivative with respect to Λ_i in order to capture the impact of having different degrees of economic target concerns Λ_i or types changing in the direction of $S \to G \to L$.:

$$\frac{\partial S_i^=}{\partial \Lambda_i} = \frac{\left(x_i^C\right)^{1/n}}{1-\delta} - \left(\frac{1}{n+1}\left(1+\Lambda_i-(n-1)x_i^C\right)\right)^{1/n} - \left(\frac{n+1}{n}\right)\frac{\delta}{2\left(1-\delta\right)}(1/n)^{1/n}\left(\frac{1+\Lambda_i}{2}\right)^{1/n} \tag{34}$$

Any country's sustainability decreases as its economic target concerns increase, $\frac{\partial S_i^=}{\partial \Lambda_i} < 0 \Leftrightarrow$

$$\underbrace{\left(x_i^C\right)^{1/n}}_{b_i^C} < (1-\delta)\underbrace{\left(\frac{1}{n+1}\left(1+\Lambda_i-(n-1)x_i^C\right)\right)^{1/n}}_{b_i^D} + \frac{\delta}{2}\left(\frac{n+1}{n}\right)\underbrace{\left(\frac{(1+\Lambda_i)}{2n}\right)^{1/n}}_{b_i^N}. \tag{35}$$

By proposition 2, we know that if all countries sustainability functions decrease, then the most cooperative emissions countries can sustain increases, completing the proof.

■

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