Unilateral emissions mitigation, spillovers, and global learning*

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Abstract

What's the role of unilateral measures in global climate change mitigation in a post-Durban, post 2012 global policy regime? We argue that under conditions of preference heterogeneity, unilateral emissions mitigation at a subnational level may exist even when a nation is unwilling to commit to emission cuts. As the fraction of individuals unilaterally cutting emissions in a global strongly connected network of countries evolves over time, learning the costs of cutting emissions can result in the adoption of such activities globally and we establish that this will indeed happen under certain assumptions. We analyze the features of a policy proposal that could accelerate convergence to a low carbon world in the presence of global learning.

JEL Classification: Q54, F53, Q55, O33.

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1 Introduction

The Copenhagen Accords[1], while non-binding, sets out the foundations of a framework for the unilateral actions of all the parties relating to mitigation and adaptation activities. Under what conditions do such unilateral measures also provide an adequate foundation for global climate change mitigation building on cross-country spillovers and learning?[2] Evidently individuals within countries will, at any point in time, compare the benefits and costs of cutting emissions unilaterally; however, the pattern of cross-country spillovers (the structure of connections between countries in a global network), underpinned by appropriate policy mechanisms, will also influence how learning takes place and the outcome to which such learning converges. Beyond Copenhagen, in the presence of a post-Durban, post 2012 global policy regime with a seemingly limited multilateral process this may offer a constructive avenue for progress.

We note that participation and compliance in a broad-based multilateral initiative

[1] The text that came out of the Copenhagen meeting hosted by the United Nations Framework Convention on Climate Change (UNFCCC) in December 2009 is referred to as the Copenhagen Accords.

[2] An earlier literature on learning and climate change, in contrast to the approach adopted here, focuses on the role of uncertainity of climate damage and learning by delaying action. See Kolstad (1996),Ulph and Ulph (1997) and O'Neil et al (2006). The analysis contained in Barreto and Kypreos (2004) is the closest to our focus here.

that aims to go further than what individual countries are unilaterally willing to commit has been hard to achieve under UNFCCC process. Any broad based global cooperation that requires nations to commit to emission cuts beyond what nations are unilaterally willing to undertake is unlikely to be stable (i.e. immune to deviations by a nation or a coalition of nations).[3]

Why would individual agents undertake unilateral emission cuts within a country even in the absence of a global agreement to cut emissions? This could happen because it is in the self-interest of relevant economic actors (e.g. adaptation to the local impacts of climate change) to undertake unilateral measures that also result lower emissions. Nevertheless, the diversity of unilateral initiatives reflects a underlying heterogeneity of interests, beliefs, motivation at the level of countries, regions and groups (e.g. signalling certain forms of self-enforcing collective identity (Olson (1971)) or just a "warm glow" (Andreoni (2006)). The cost of cutting emissions could limit, at any one point of time, the size of the group of

[3]By delaying participation or by not complying with a global agreement to cut emissions, a deviating country or a coalition of such countries can continue to capture the short-term benefits from continuing with high carbon economic activities, but pass a significant portion of the costs to others (other countries, future generations): Free riding in the presence of negative externalities limits the scope for cooperation in the presence of weak property rights. Shapley and Shubik (1969) and Starrett (1973) were among the first to make this point.

individuals, within a given country, who would be willing to unilaterally undertake costly emissions cuts. As a consequence, although a national level commitment to emission cuts may not emerge as the outcome of majority voting, unilateral measures may then exist at various subnational levels.

This paper studies the possible interplay between unilateral measures and global climate change mitigation aiming to build on the initiative from Copenhagen. Our starting point is the observation that although national level commitments to unilateral emission cuts have been hard to achieve, there is a variety of existing unilateral measures to cut emissions already underway. In a companion paper (Chatterji, Ghosal, Whalley and Walsh (2012)), we document the extent, form and variety, some at a national level but mainly at a subnational (regional/urban/individual) level, of existing unilateral measures. Examples of such unilateral measures include community based programs such as free bicycle plans, as in Copenhagen, Denmark, or watershed renewal programmes, such as in rural communities bordering major rain forests as in Mexico. As such most unilateral measures consist of a mix of local adaptation together with increasing capacity in renewables and a reduction of energy consumption either directly and indirectly (via energy saving techniques, infrastructure renewal and increased efficiency). The objectives of such measures are typically more heavily focused on reduced energy consumption (which implies reduced emissions) rather than directly on emission mitigation.

Switching to low carbon activities requires the diffusion of low carbon technologies primarily in key sectors such as energy, infrastructure, transport and industry. The use of these technologies in one nation, or a region/city within a nation will generate positive transnational spillovers (Human Development Report (2008)). When a small group of cities unilaterally introduces measures to induce more use of public transport it also lowers the cost of adopting such a policy in other cities elsewhere in the world and therefore initiates a learning process that could lead to a greater use of public transport globally in urban areas. At a national level, reducing the cost of generating electricity by wind/solar power potentially benefits economic actors in other countries and not just within the borders of the country where the innovation takes place.

A case in point is the argument that the initial commitment to cut 50% of CFCs in the Montreal protocol was critical to its success as it lowered the costs of making even bigger reductions by providing a real incentive for the development of substitutes to CFCs

(Benedick (1998)). Thus, although there is a difference in scale, the events surrounding the Montreal Protocol may be taken as a precedent for the potential of such a mechanism. The point is that unilateral commitments induce innovation, by creating a market for such innovations and in technologies that could lower the cost of switching to low carbon economic activities across different locations[4].

We build a formal model where we analyze the conditions under which learning results in global adoption of low carbon technology in finite time. In our model, countries initially are unable to agree to a global agreement to cut emissions. Individuals within a country learn about the cost of cutting emissions which decreases as the fraction of individuals, globally, evolves over time. Under our assumptions, an individual decision to cut emissions is irreversible. When countries make a collective decision to cut emissions by majority voting (and under our assumptions, such a decision is irreversible), we show that such learning in a network of strongly connected countries, provided it builds on unilateral initiatives in at least two countries , will, over time, deliver a global switch to

[4]The scope of such positive externalities may, however, be limited by issues of technology transfer and absorptive capacity across locales in the face of binding political and cultural constraints.

low emissions.[5]

Importantly, we prove a possibility result i.e. establish, under a strong set of assumptions (explained and examined in greater detail in section 3 below) what *could* happen and do not make any claims that the scenario studied in the model *will* necessarily happen unless appropriate policy mechanisms are put in place.

Drawing on the results of the model, we discuss how policy design could also affect global learning by impacting both the structure, and strength, of interactions between countries and underscore the goal of convergence to a global low emissions regime. Our result suggests that key features a successful policy regime that builds on unilateral initiatives via global learning should include measures for developing a platform for exchange of information and subsidized monitoring, strengthening spillovers across subnational actors in different countries as well as a new global IP regime involving subsidized, targeted technology transfer of low carbon activities[6].

[5] I.e. one where two countries (e.g. Norway and China), even if not directly linked, are always indirectly linked to each other via an intermediary chain of other countries (Norway, US, Mexico, India, China).

[6] There are two further issues that are beyond the scope of the current paper and which open up further issues relating to policy design: (i) the optimal mix of local and central level actions within each country, (ii) the interaction of unilateral initaitives and global negotiations to cut emissions. These are matters that we aim to address in future research.

A specific policy document presented by the G77 and China in Copenhagen under paragraph 11 of the Copenhagen Accords addresses similar issues. This proposal sets out a fast-track process for the diffusion of relevant technologies to either high emissions areas or those places where adaptation is already becoming a critical concern. We critically examine key features of this proposal in light of our formal results.

The remainder of the paper is structured as follows. Section 2 briefly sets out some examples of unilateral measures. Section 3 sets out the model under which global learning, building on existing unilateral measures, leads to a low emissions global paradigm. Section 4 discusses the possible implications of this model for the post-Durban process going forward, while the last section concludes.

2 How extensive are unilateral measures on emissions mitigation?

In this section we provide some examples of unilateral measures which have been taken worldwide towards climate change. In ongoing global negotiations, the major participant countries have simultaneously adopted national action plans for combating climate change which also involve extensive use of unilateral commitments.

To some extent, these unilateral commitments are mechanisms for the implementation of proposed multilateral commitments, but in other ways they are different. Thus, in the EU, there is a commitment to a 20-20-20 program, which involves a 20% reduction in emissions and 20% of energy to come from renewables by 2020. This is independent of any subsequent multilateral commitments, though the EU has offered to go further to a 30% emissions reduction if other entities were to match. Similar initiatives can also be found in the case of China, where there are extensive commitments to a 20% energy consumption reduction relative to 2005 by 2020, a 45% reduction in carbon emissions relative to GDP by 2020 and also a similar 20% commitment to renewable energy. These forms of commitments, interestingly, also seem to involve deeper commitments by smaller countries. One striking case is Norway, which has committed itself to become a zero carbon economy by 2050.

These examples are national but seemingly go substantially beyond what countries are jointly willing to commit to multilaterally. And beyond the national level, there are also many further commitments also being made by sub-national and local levels by governments, community based organizations, businesses, and even by individuals.

At the state and inter-state levels of government in the US we see multi-state agreements such as the Mid-West Greenhouse Gas Reduction accord, the Regional Greenhouse Gas Initiative, the Western Climate Initiative and the Western Governors' Association – Clean and Diversified Energy Initiative. Setting restrictions on CO_2 emissions by specified dates is the content of all of these save the Clean and Diversified Energy Initiative, which sets a 30000 MW production goal by 2015 for renewable energy among member states as well as more long term goals. These agreements are not restricted to the US. Several Canadian provinces have also signed onto some of these agreements, Ontario and Alberta being examples. Within Canada as well, there is a cap and trade plan being negotiated between Ontario and Quebec, two of the top three emitting provinces. Individual state efforts in North America have the common feature that nearly all states and provinces have programs designed to improve energy efficiency, although direct emissions reduction efforts are the most common activity. Similar initiatives exist in Australia, India and China.

It is also not unusual in Europe for individual cities to now have emissions reduction targets by specified dates. These could involve community based programs such as free bicycle plans, as in Copenhagen, Denmark or watershed renewal programmes, as in rural communities bordering major rain forests as in Mexico, and community information monitoring schemes as in sophisticated software which tracks carbon from individual houses based on lifestyle and energy use (the idea being that increased knowledge will change people's behavior).

City level emissions mitigation efforts tend to lend equal weight to adaptation and mitigation, usually blending the two in proposed plans. In New York City for example, a major initiative is underway to improve energy efficiency and reduce emissions of all sorts, including a 30% reduction in greenhouse gas emissions. The focus is on replacing older infrastructure with new and more energy efficient technology which will also prepare the way for any water, food, or natural disasters to be dealt with, and also to replace existing cars with more fuel efficient ones and to increase the number of trees and parks within the city. Toronto, Canada has also engaged in energy efficiency upgrading for many of its buildings and infrastructure projects. Otherwise the plan of action is very different, with Toronto seeming to prefer development of local sources of renewables over the larger infrastructure upgrading projects and promoting green roofs heavily. Munich in Germany has a plan very similar to Toronto's, with the added financial innovation of weather derivatives regarding the weather's impact in generating renewable power in order to help manage the risks involved[7]. Similarly, London, UK, has a plan that focuses most heavily on energy efficiency upgrading, with projects on renewables.

In China, Shanghai has invested 80 billion Yuan (11.6 billion USD) in environmental protection projects. The city, which is near to sea level has increased plant and tree coverage to help ward off erosion as the threat of floods increases and is also intensely focused on upgrading and installing infrastructure to ensure the city's water supply. The plan also provides incentives for promoting green industries within and around the city and also has a goal for decreasing the volume of vehicles on the roads by 65%.[8]

A common thread in these unilateral emissions reduction initiatives (direct and indirect) is a focus on renewables, energy efficiency upgrading and infrastructure renovation at a city level within the global sphere. On the other hand, more so than at high levels of government, a clear focus on adaptive measures is also interwoven into these policies.

[7] http://www.munichre.com/en/ts/innovation_and_insurance_trends/windmills_against_climate_change/default.aspx

[8] http://en.chinagate.cn/development/environment/2008-12/15/content_16950071.htm

Commitments are also made at a business level, with new businesses offering what is needed for other businesses, communities and individuals to "go green"[9]. Because of the wider social/political commitment to emissions reduction, it becomes good business to characterize products as emissions sensitive, contributing to significant emissions reductions. Finally, similar actions can be taken at an individual level.

These unilateral actions being undertaken to combat climate change and reduce carbon emissions around the world are both diverse and in constant flux. The examples given in this paper are representative samples of the levels and types of unilateral actions occurring. For the purpose of the discussion here, the key point is that they jointly create a pool of experience with a range of possible measures which can spur global learning and further mitigation. Unilateral measures and global learning can be the key to wider mitigation to follow on.

[9] Recent estimates set the "green" industry worldwide at roughly 360 billion USD, with estimates that this could grow rapidly to 650-750 billion USD by late 2015. See http://english.cw.com.tw/article.do?action=shpw&id=10399&offset=0.

3 Unilateral Measures and Global Learning

In this section, we examine the conditions under which global learning, building on the positive spillovers generated by unilateral actions within a strongly connected global network of countries, delivers ever deepening emission cuts over time and convergence to a low carbon world in finite time.

3.1 Rationale for unilateral measures

A number of the examples discussed in the preceding section make the point that it could actually be in the self-interest[10] of relevant economic actors to undertake unilateral measures that also result lower emissions. Nevertheless, the diversity of unilateral initiatives reflects a underlying heterogeneity of interests, beliefs, motivation at the level of countries, regions and groups.

Certain forms of collective identity can be self-enforcing in that conditional on other individuals accepting the same collective identity, it is in the self-interest of any one individual not to deviate, a point emphasized by Olson (1971) in his work on collective

[10] Examples include adaptation to the local impacts of climate change, ensuring energy security, halting the process of desertification, local development needs.

action[11]. A different possibility is that the agent who cuts emissions obtains a "warm glow" as discussed in the literature on philanthropy (see, for example, Andreoni, 2006) from the act of cutting emissions.

Straightforwardly, an economic agent will unilaterally cut emissions if the perceived private benefit (whatever its source, for example signalling a certain collective identity from "going green", or "warm glow") is greater than the cost of cutting emissions. Clearly, the cost of cutting emissions could limit, at any one point of time, the size of the group of individuals, within a given population, who would be willing to unilaterally undertake costly emissions cuts. Although a national level commitment to emission cuts may not emerge as the outcome of majority voting, unilateral measures may then exist at various subnational levels.

[11] A related rationalization of unilateral initiatives lies in "rule utilitarianism" (Harsanyi (1977)) where individuals act to conform to a specific rule given that some group of other individuals also conform to the relevant rule. Unilateral measures in a given group can be rationalized if each individual in that group finds its optimal to cut emissions given that all individuals in that group conform to the rule of cutting emissions.

3.2 A formal model of unilateral measures, global learning and cumulative emission cuts

Before we present the formal model, it might help to have an *example* that would fit the scenario studied in the model. In the OECD, Europe and in rapidly growing developing countries, a small set of key 3-4 industries (power generation foremost) account for over 50% of industrial emissions. Adoption of low emission technology standards in these key industries within a small group of OECD countries will significantly lower the costs of adopting standards in other countries both within, and without, the OECD. Heal (1993) argues that as one country undertakes even limited emission cuts it incurs a variety of costs (e.g. R and D investments, retooling) that are "sunk" in nature. However, once the new low carbon technology has been developed, it can be made available to another country at a relatively lower cost. Moreover, given the larger market, there are greater private incentives to innovate in both countries leading to deeper emission cuts within the two countries and at some point, depending on the structure of spillovers between countries, inducing emission cuts by a third country and so on. The general point is that as one country cuts its emissions, the cost of cutting emissions for other countries may, as a function of the structure of spillovers between countries, fall as well thus making emission cuts more worthwhile in these latter countries.

In the model, with discrete time intervals which go from $t = 1, 2, ..., \infty$, there are $n = 1, ..., N$ countries. Each country consists of a number of individuals (also referred to as economic agents) of mass one. At t, $e_{n,j}^t \in \{0, 1\}$ denotes the emissions of greenhouse gases by individual j belonging to country n so that at any $t, e_{n,j}^t = 0$ corresponds to adopting low carbon activities while $e_{n,j}^t = 1$ corresponds to persisting with high carbon activities. Let γ_n^t denote the fraction of agents in country n who choose $e_{n,j}^t = 0$ in time period t. Then, $e_n^t = (1 - \gamma_n^t)$ is the total level of emissions in country n at time period t. Let $E^t = \sum_i e_n^t$ denote the level of global emissions at time t.

We model the preferences and behavior of individuals within a country as follows. Assume that individual j in country n obtains a private benefit from cutting emissions $b_j \in [0, B]$, $B > 0$ with individuals within a country uniformly distributed on the interval $[0, B]$. Consistent with our earlier discussion, we interpret this private benefit to the individual from cutting emissions as derived from either group membership or a "warm glow" or just the direct benefit from successful local adaptation.

In our model, the cost[12] of cutting emissions in country n at time t is a function of a weighted sum of the fraction of individuals $\gamma_{n'}^{t-1}$ who cut emissions all other countries n' in preceding time period $t-1$. The weight attached to country n' is denoted by $\rho_{n,n'}$, $0 \leq \rho_{n,n'} \leq 1$: $\rho_{n,n'}$ is a parameter that captures the spillover from country n' to country n. We assume that $\rho_{n,n} = 1$. So $c_n^t = c_n \left(\sum_{n'} \rho_{n,n'} \gamma_{n'}^{t-1}\right)$ denotes the cost of cutting emissions to individual located in country n given that a proportion $\gamma_{n'}^{t-1}$, $n' = 1, 2, ..., N$ of individuals in all countries have already cut emissions at $t-1$.

Next, we formally define the network structure over countries as follows.

Definition 1. (Network Structure) We say that country n is connected to country n' if $\rho_{n,n'} > 0$. Define a directed graph (network structure) over N where the vertices are countries and the arc (n, n') exists iff n is connected to n'. A path in a directed graph is an ordered collection of arcs and vertices in which all vertices are distinct.

Some examples might help clarify the structure of connections between countries in a global network:

[12] These costs could be financial costs, lowering the relative costs in terms of the effort or time sacrificed to do the 'green' thing i.e. making it easier in terms of the physical and cognitive effort involved to do the 'green' thing rather than the more carbon intensive equivalent action.

1. All countries are linked to each other. In this case, the complete network, $\rho_{n,n'} > 0$ for all $n, n' = 1, ..., N$. Note that in this case no one country is pivotal in generating spillovers.

2. There is a single country (say, country 1) which is pivotal. Country 1 has two way links with all countries but no direct links exist between any other pair of countries. Nevertheless, all countries are indirectly linked to each other are linked to each other as there is a path between any two countries via country 1. Country 1 can be thought of as a large OECD economy like the US. Formally, in this case, $\rho_{n,1} > 0$, $\rho_{1,n} > 0$ but $\rho_{n,n'} = 0$ for $n \neq n'$ whenever $n' \neq 1$. Note that $\rho_{n,1} \neq \rho_{1,n}$: we allow for the possibility that the strength of the spillover on a small country from the US cutting emissions could be different from the converse.

3. There is a small group of countries (say countries $1, 2, 3, ..., K$) that are pivotal. In this case, each pivotal country is linked to another pivotal country. Countries that are not pivotal can be divided into K non-intersecting groups, one for each pivotal country so that there is a two way link between country 1 and each country in the group corresponding to country 1 and so on. Finally, no no pair of non-pivotal are directly linked although there

is a path connecting any two countries via some subset of pivotal countries. Countries in the G20 could be thought of being pivotal. Formally, consider a partition of the set of countries $N_1, N_2, ..., N_K$ (each non-empty) such that $\rho_{n_r,n_s} > 0$, $\rho_{n_s,n_r} > 0$, for some $n_s \in N_s$ and some $n_r \in N_r$, $r \neq s$, $r, s = 1, ..., K$, $\rho_{n_s,n'} > 0$, $\rho_{n',n_s} > 0$ whenever n_s, $n' \in N_s$ but $\rho_{n',n''} = 0$ otherwise.

In each of the above examples, even if a pair of countries are not directly linked, there is, nevertheless a path indirectly linking the two countries. The following definition provides a formal definition of networks that satisfy this property:

Definition 2. (Strongly connected networks) The directed graph over countries is strongly connected if for every pair of distinct vertices (n, n') there exists a path connecting n to n' i.e. between any two countries n, n', there is a chain of countries $n_0 = n, ..., n_S = n'$ with $\rho_{n_s,n_{s-1}} > 0$, $s = 1, ..., S$: in this case, we say that countries are globally strongly connected.

Given the global network structure over countries, the spillover to the costs of cutting emissions in country n at time t by emission cutting activity elsewhere is the weighted sum of the fraction of individuals who have cut emissions in the preceding period $\sum_{n'} \rho_{n,n'} \gamma_{n'}^{t-1}$.

Specifically, both whether or not $\rho_{n,n'}$ is strictly positive and its magnitude for given pair of countries n, n' will be a consequence of the use of appropriate policy mechanisms that build on positive technological spillovers across countries. Such a policy will leverage on the impact of positive technological/institutional externalities to facilitate innovation, technology transfer and adoption of low emission activities both within a country and across countries. Subsidized targeted technology transfer may alter the participation constraints of nations over time. How such a policy relates to existing initiatives will be discussed in the following section.

We make the following assumptions:

Assumption 1: Countries $1, ..., N$ belong to a strongly connected global network.

Assumption 2: In each country n, $c_n(.)$ is a continuous strictly decreasing function on $[0, 1]$ and two boundary conditions: $c_n(0) < B$ and $c_{n'}(0) < B$ for at least two countries n, n' and $c_n(1) = 0$ for all countries $n = 1, ..., N$. For later reference, we label a cost function that satisfies assumption 2 as an *admissible* cost function.

Assumption 1 requires that the global network of countries remains strongly connected over the duration of the learning process studied below i.e. countries commit to, and implement, policy mechanisms that ensure the structure and strength of links between countries remains unaltered over time. This is, admittedly, a strong assumption and we will discuss (in section 3.3. below) the robustness of our results to this assumption below.

In our model, individuals in each country n learn the cost of cutting emissions as the fraction of individuals cutting emissions in other countries belonging to the global network evolves over time. When the cost function is admissible, we are able to show that there is a pair of countries where there will be an unilateral commitment by a group of individuals to cut emissions, that such unilateral actions lowers, over time, the cost of adopting low carbon activities for other individuals both within country n and other countries as well, and further, if all individuals within a country are choosing to cut emissions then no individual within the same country will deviate to the high carbon activity. Again, we will discuss (in section 3.3 below) the robustness of our main result to the assumption that $c(.)$ is admissible.

We assume that an individual i in country n behaves myopically and will voluntarily choose to cut emissions at time t whenever $b_j - c_n \left(\sum_{n'} \rho_{n,n'} \gamma_{n'}^{t-1}\right) \geq 0$. When $c_n(.)$ is a continuous, strictly decreasing function for each n, it straightforward to note that once an individual voluntarily chooses to cut emissions at time t, he or she will continue to voluntarily cut emissions in all subsequent time periods i.e. if for some individual j in country n, $e_{n,j}^t = 0$ is the optimal action at some time t, then $e_{n,j}^{t'} = 0$ continues to be the dominant action for all $t' \geq t$. Therefore, in our model, although an individual behaves myopically, once the decision to cut emissions is made, it is irreversible. We note that under our assumptions, it is globally efficient to set $e_{n,j}^t = 0$ for all individuals j and countries n at each t.

In each country n at each t, individuals collectively decide, via majority voting, between two alternatives: (i) all individuals within the country switch to zero emission activities, or (ii) only those individuals who voluntarily choose to do so switch to low emission activities. Therefore, a country n will commit to cut emissions to zero in period t iff $\gamma_n^t \geq \frac{1}{2}$: we will discuss the robustness of our main result to this assumption below. A straightforward consequence of the fact that each individual's decision to cut emissions is irreversible is that a collective decision, via majority voting, by country n at time t to cut emissions is also irreversible.

We will further assume that no country will collectively commit, via majority voting, to cut emissions in the initial time period i.e. $0 \leq \gamma_n^0 < \frac{1}{2}$ for all countries n. As no country has a majority in favour of cutting emissions, a global agreement to cut emissions in the initial time period will not materialize even though it is globally efficient to do so. The divergence between private payoffs and global payoffs in our model reflects both the wide-spread negative externalities (the medium term damage caused by global warming) resulting from continued high emission activities and the myopic behavior of individuals.

Let $g_n^t = \{j : b_j - c_n^t \geq 0\}$ denote the group of individuals in country n for whom it becomes the myopically dominant action to cut emissions at time t within a nation n with $m(g_n^t)$ denote the corresponding mass[13]. Define the function

$$G_n^t = G_n\left(\sum_{n'} \rho_{n,n'}\gamma_n^{t-1}\right) = m\left\{j : b_j - c_n^t \geq 0\right\}.$$

Thus, G_n^t denotes the proportion of individuals in country n for whom it becomes a myopically dominant action to cut emissions at t.

The evolution[14] of γ_n^t within each country n over time is assumed to be, for $t \geq 2$, by

[13] I.e. the measure of agents belonging to g_n^t.

[14] There is a large literature on learning in networks (see, for example, Jackson and Yariv (2007) for a synthesis and Jackson and Yariv (2011) for a survey). While the model we study here shares a number of common features with these other models, there are at least two key differences: (i) in our setting, learning occurs both within a node and other nodes (i.e. individuals within a country as well as across countries), and (ii) the incentives for individuals to cut emissions within a node (country) at time t

the system of difference equations :

$$\gamma_n^t = \min\left\{\gamma_n^{t-1} + \lambda_n\left(G_n^t - \gamma_n^{t-1}\right), 1\right\}, \; n = 1, ..., N, \; (1)$$

where λ_n, $0 < \lambda_n \leq 1$, is a measure of inertia in learning within country n. Not all individuals within country n who benefit from switching actually do so- this could be due to variety of factors such as habit formation, lack of awareness and information etc. What is essential for our main result is that $\lambda_n > 0$ although we will also show that the magnitude of λ_n will matter in determining the speed of convergence to a global low carbon regime. Note that (1) is a system of difference equations that cannot, in general, be reduced to a collection of uncoupled difference equations, one for each country n.

Will each country eventually be in a position to commit to cut emissions?

The following proposition states the conditions under which global learning, building on unilateral actions within a pair of countries, delivers a switch to low emissions in finite time:

Global Learning Result: *Under assumptions 1 and 2, the learning dynamics de-*

depends on the entire distribution of the fraction of individuals who cut emissions over all nodes and not just on either the aggregate fraction (in the network as a whole) or the fraction in neighboring nodes.

scribed by (1) *has a unique, stable*[15] *fixed point* $(1, ..., 1)$. *Further, as long as the collective decision to cut emissions within each nation is made by majority voting, there exists* $\hat{t}_n$, *decreasing in* λ_n, $\rho_{n,n'}$, $n, n' = 1, ..., N$, *such that country* n *will commit to cut emissions for all* $t \geq \hat{t}_n$, *with* $e_n^t = (1 - \gamma_n^t)$ *for all* $t < \hat{t}_n$*: a global agreement to cut emissions will emerge at* $\hat{t} = \max_i \hat{t}_n$ *and remain in place in all subsequent time periods.*

Proof. Under the assumption that, in each country n, the private benefit b_j from choosing $e_{n,j}^t = 0$ is uniformly distributed over $[0, B]$ and the assumption that $c(.)$ is a continuous, decreasing function, it follows that the map $G = \{G_n(x) : n = 1, ..., N\}$, $G : [0, 1]^N \rightarrow [0, 1]^N$, is continuous and increasing on $[0, 1]^N$ as is the learning dynamics described by (1). Further, by construction $G_n(x) = 1$ for all $x \geq 1$, $n = 1, ..., N$. Therefore, the vector $(1, ..., 1)$ is always a fixed-point of $G = \{G_n(x) : n = 1, ..., N\}$ and hence, of the learning dynamics described by (1).

Under our assumptions, there are at least two countries n, n' with $\gamma_n^0 > 0$ and $\gamma_{n'}^0 > 0$ and as countries are globally strongly connected, for each country k, it follows that

[15] Under our assumptions, there are at least two countries n, n' with $\gamma_n^0 > 0$ and $\gamma_{n'}^0 > 0$. Therefore, the global stability of the fixed point $(1, ..., 1)$ under the learning dynamics (1) requires that $\lim_{t \to \infty} \gamma_n^t = 1$ for all $\gamma_n^0 \geq 0$ (with strict inequality for at least two countries), $n = 1, ..., N$.

$G_k^t = G_k\left(\sum_{n'} \rho_{m,n'}\gamma_{n'}^0\right) > \gamma_k^0$. Whenever $\gamma_{n'}^t > 0$, for some country n' at some t, as there is a path connecting each country n to country k, $k \neq n$, there exists $t' \geq t$ such that $G_n^t = G_n\left(\sum_{n'} \rho_{n,n'}\gamma_{n'}^{t'-1}\right) > \gamma_n^{t'-1} \geq 0$: $t = t'$ if $\gamma_n^t > 0$ and $\rho_{n,k} > 0$, otherwise $t' > t$, $t' \leq t + s$ where s is the minimum number of vertices (the minimum taken across all the paths connecting n to k) between n and k. It follows that $(1, ..., 1)$ is the only fixed-point of G and the learning dynamics described by (1). Consider $\{\gamma^t : t \geq 1\}$ the sequence generated by an iterated application of the RHS of (1). Then, $G_n^t = G_n\left(\sum_{n''} \rho_{n,n'}(1-\varepsilon)\right) > 1 - \varepsilon$, $0 < \varepsilon \leq 1$, and by continuity of G, for each country n, $\sup_t \gamma_n^t = 1$ and as $\{\gamma^t : t \geq 1\}$ is a component-wise increasing sequence, $lim_{t\to\infty}\gamma_n^t = 1$ for all $n = 1, ..., N$: therefore, $(1, ..., 1)$ is stable under the learning dynamics (1).

Let $\hat{t}_n = \inf\left\{t : \gamma_n^t \geq \frac{1}{2}\right\}$. Therefore, for all $t \geq \hat{t}_n$, $\gamma_n^{\hat{t}_n} \geq \frac{1}{2}$ and a global agreement to cut emissions will emerge at $\hat{t} = \max_n \hat{t}_n$ and remain in place in all subsequent time periods. As the RHS of (1) is increasing in λ_n, $\rho_{n,n'}$, $n, n' \in N$, for each country n, $\hat{t}_n$ is decreasing in λ_n, $\rho_{n,n'}$ $n, n' \in N$. ■

The proof of our result is based on the idea that the fraction of individuals in each country switching to the low carbon activity is a non-decreasing sequence over time because the decision to cut emissions is irreversible. Furthermore, with admissible costs, the fraction of individuals in each country making the switch to a low carbon activity is a strictly increasing sequence over time because unilateral initiatives are undertaken in at least two countries and the graph over countries is strongly connected. Therefore, there can be no points where the process gets stuck until all individuals in each country has switched to the low carbon activity.

The above result[16] implies that as long as countries are globally strongly connected and the cost function is admissible global learning will eventually occur and a majority of voters in each country n will, in finite time, voluntary choose vote to commit to cut emissions leading to a global agreement to cut emissions.

However, our result builds on strong assumptions. Next, we examine how our main result is affected when the underlying assumptions are relaxed.

[16] It is worth pointing out that the formal model we study is different, both in terms of motivation and in terms of formulation, from the model of international environmental agreements developed by Barrett (1994). Barrett presents a multi-country model in which agreements on international environmental regulations are enforced through agreed trigger mechanisms. These involve joint agreement to increase pollution (emissions) if any country deviates from its agreed level. Our model has no formal international agreements and agents in our model behave myopically, Barrett's model has no learning and doesn't examine the impact of network structure on global mitigation efforts.

3.3 Clarification of the Global Learning Result

This Global Learning Result suggests the possibility that, with sufficiently strong spillovers, the unilateral adoption of climate change mitigation technologies at a local level by independent jurisdictions can result in a universal adoption of such technologies, and establishes that this can indeed happen under certain assumptions. However, we do not establish that global learning will necessarily lead a low carbon world.

We examine the role played by the assumptions made by us below:

1. **The collective decision to switch to a low emissions is made by majority voting**: A key feature of the model is that once at least 50% of a population switch to a low emission technology then 100% of that population use that low emissions technology for ever more. There are a number of very strong implicit assumptions here:

(i) It is assumed that a majority decision to adopt a technology is equivalent to 100% use of that technology. But even if the majority of individuals in a country vote to install, say, windfarms, it may not be feasible for the majority to force everyone in the country to use that source of energy. Of course the use of dirty technology could be taxed (or made very expensive by other measures) but this is a strong assumption: there is an elision between technology spillovers and behavioral spillovers implicit in this assumption. However, it is worth noting that what is crucial for our result to go through is that there exists a threshold ω, $\frac{1}{2} \leq \omega < 1$, so that when the proportion of individuals within each country cutting emissions was greater than or equal to ω there would be a collective switch to cutting emissions. Such a threshold could be thought of as a purely technological threshold (i.e. the cost of cutting emissions drops discontinuously to zero for all individuals in a country once the fraction choosing voluntarily to cut emissions exceeds a certain percentage (which is likely to be higher than 50%). If no such threshold exists, then a weaker form of our result would still go through: the learning dynamics described by (1) would still converge to a low carbon world: however, the global switch will not occur in finite time although it could still be very close.

(ii) Second, under the assumption that in each country n, $c_n(.)$ is a strictly decreasing function on $[0,1]$, the switch to a low carbon world is irreversible. However, technologies do get mothballed if the economic circumstances that make them viable/profitable change. The first implication of our assumption on the cost function is that all learning within and across countries is complementary so that G is increasing on $[0,1]^N$: all internal and external learning will cause and increasing proportion of individuals within a country to cut emissions (or at least, any negative influence will tend to be overridden by the positive influences). Provided there is a threshold ω, $\frac{1}{2} \leq \omega < 1$, so that when the proportion of individuals within each country cutting emissions was greater than or equal to ω there would be a collective switch to cutting emissions, it is straightforward to note the Global Learning Result doesn't require that G to be increasing over the whole of $[0,1]^N$. What is essential for the argument in this case is that any fixed-point of G is greater than (in the usual vector ordering) the vector $\{\omega, ..., \omega\}$ which requires that G is increasing on $[0,\omega]^N$ so that the global learning result is robust to scenarios where negative influences eventually dominate positive influences when a sufficiently large fraction of individuals within each country have already switched to cutting emissions.

(iii) Finally there is the assumption that governments can commit to future policies. But even if a region elects a very green government one period, it may be that future governments are far less green and may undo policy and so make a technology less viable. Of course, anticipating this possibility, raises interesting questions about what factors drive private decisions to adopt cleaner technologies whose profitability might depend on policies chosen by governments far into the future.

The Global learning Result requires not only that all countries belong a globally strongly connected network but also that the network structure remains unaltered over the duration of the learning process. The costs and credibility of policy mechanisms (e.g. tax policy) that could maintain the structure and the strength of links between countries isn't modelled. Clearly our main result wouldn't hold if governments could alter policy so that the links between countries could be severed so that network structure fails to be strongly connected thereby interrupting the learning process. Although it falls outside the scope of our formal model, if agents could anticipate such future changes in policies, a number of issues relating to the factors that drive individual decisions to adopt low emissions technologies would arise.

2. **Countries are connected to each other in a globally connected network.** To understand the importance of the underlying network structure (the pattern of spillover effects across countries) in driving global learning to the point where countries commit to switching to low emissions, it is useful to consider the polar opposite case, where $\rho_{nn'} = 0$ for all $n \neq n'$: in this there are no cross-country spillovers and each country is isolated

(there are no arcs between countries) and all learning occurs within each country. In this case, the evolution of γ_n^t within each country n over time is described, for $t \geq 2$, by the equation:

$$\gamma_n^t = \min\left\{\gamma_n^{t-1} + \lambda_n\left(F_n\left(\gamma_n^{t-1}\right) - \gamma_n^{t-1}\right), 1\right\} \;\; n = 1, ..., N \qquad (2)$$

where $F_n(.) = G_n(.)$ on $[0, 1]$. Clearly, in this case, (2) is a system of difference equations that can be reduced to a collection of uncoupled difference equations, one for each country n each of which can be analyzed separately. In this case, will each country eventually be in a position to commit to cut emissions? The answer in general is no: learning within country n may never result in country n, as a whole, switching to low emissions[17].

It is straightforward to construct examples where $lim_{t\to\infty}\gamma_n^t < \frac{1}{2}$ for most countries when countries aren't globally connected. Suppose $0 < \gamma_1 < \frac{1}{2}$, $\gamma_n = \rho_{n1} = 0$, $n \neq 1$. Then, no country other than country 1 moves away from 0 as country 1 is isolated (i.e.

[17]Let $\gamma_n^* = \min\{\gamma \in [0, 1] : F_n(\gamma) = \gamma\}$ is smallest fixed point of the map $F_n : [0, 1] \to [0, 1]$. γ_n^* is well-defined as 1 is always a fixed point of $F_n(.)$ and the set of fixed-points of $F_n(.)$ is closed subset of a compact set and hence, compact. Let $\{\gamma_n^t; t \geq 1\}$ denote the sequence generated by an iterated application of the RHS of (2) with $\gamma_n^0 \geq 0$ and $\gamma_n^* \geq \gamma_n^0 > 0$. Clearly, if $\gamma_n^0 = 0$, country n never moves away from 0. If $\gamma_n^0 > 0$, then by continuity of $F_n(.)$, $\sup_t \gamma_n^t = \gamma_n^*$ and as $\{\gamma_n^t; t \geq 1\}$ is an increasing sequence, $lim_{t\to\infty}\gamma_n^t = \gamma_n^*$. Thereforer, if $\gamma_n^* < \frac{1}{2}$, there will be no collective switch in country n to cutting emissions.

not linked to any other country) and this is the only country where unilateral actions are being undertaken. Clearly, other less extreme examples, along the above lines, can be constructed.

3. **Speed of convergence and the role of government intervention**.

Although learning in the formal model is driven by technological spillovers generated by unilateral initiatives, we do not suggest that governments should do nothing to reach cooperative agreements because local action alone will be sufficient to achieve the desired outcome. Our main result shows that the global adoption of a low carbon technology could happen by a process of purely local action. Could learning be faster if there were efforts to reach some kind of cooperative agreements wherever possible? For example, suppose $\lambda_n = \frac{1}{2}$ and $\sum_n \gamma_n^0 \geq \frac{1}{2}$. Suppose $\rho_{nn'} = \frac{1}{2}$ for all countries n, n'. Then our global learning result implies that eventually it would be the case that $\gamma_n^t \geq \frac{1}{2}$ for all countries n whenever $t \geq \hat{t}$. Note that in this case, under the learning dynamics (1) it is necessarily the case that $\hat{t} > 2$ (i.e. global learning will take at least three (or more) periods). However, if cooperative agreements between countries could ensure that $\lambda_n = 1$ and $\rho_{nn'} = 1$ for all countries n, n', then under the learning dynamics (1), it follows that

$\gamma_n^t \geq \frac{1}{2}$ for all n for each $t \geq 2$. This is clearly a best-case scenario, one where convergence is immediate: $\hat{t} = \hat{t}_n = 2$. More generally, as for each country n, $\hat{t}_n$ is decreasing in λ_n, $\rho_{n,n'}$, $n, n' = 1, ..., N$, policy interventions that increase the values of these variables (i.e. reduce learning inertia within a country and strengthen spillover effects across countries) will increase the rate at which there is global convergence to a low emissions regime.

Further, if the government in a country anticipates that unilateral actions lower the cost of switching to low emission activities for individuals in other countries, the government could incentivise a majority of individuals could be in favour of cutting emissions in that country[18] thus speeding up the process of convergence to a global low carbon regime. Countries that (a) create the largest spillover effects, either directly or indirectly, on global learning, (b) are pivotal (i.e. without whom global learning will be delayed substantially), and (c) are willing to bear the costs of being one of the first to switch to low emission activities, are more likely to act in anticipation of inducing an earlier switch to low emission activities by other countries. Moreover, such behavior will be influenced by

[18] A simillar result has been obtained in a model of farsighted network formation in Dutta, Ghosal and Ray (2005). Chatterji and Ghosal (2009) also make a similar assumption in the context of a discussion on climate change.

the strength of the spillover in learning across countries. For example, if $\lambda_n = 1$, $\rho_{nn'} = 1$ for all countries n, n', voters in country n could choose to cut emissions to zero (so that $\gamma_n^1 = 1$) anticipating that $\gamma_{n'}^t \geq \frac{1}{2}$ for all $n' \neq n$, $t \geq 2$.

In conclusion, while *even when countries initially are unable to agree to a global agreement to cut emissions, global learning could, over time, deliver a switch to low emissions in a network of strongly connected countries.* However, it is worth emphasizing that our result, like all theoretical results, suggests a possibility and establishes what will happen under a certain set of assumptions.

In the following section, we use this result to develop a policy proposal that explicitly accounts for such a possibility.

4 Global learning, the role of technology and IP, and a road to a low carbon economy

In this section, we appeal to the results of the model developed in the preceding section to motivate key features of a global policy regime that encourages the emergence of a low emissions regime by building on the positive externalities inherent in unilateral initiatives. The central mechanism is a new Multilateral Climate Technology Fund. Its aim would be to promote learning and spillovers which anyway occur.

In practice, national unilateral measures almost inevitably interact with multilateral negotiations and so a first step is to recognize these in the design of negotiations. This is evident in the Copenhagen Accord document, which enshrined unilateral reductions. Many countries announced unilateral measures in the lead up to Copenhagen and, while such commitments could be interpreted as a way of simply staking out bargaining positions, the argument we put forward is that, by including them in the Accord, it allows the Accord to become a starting point for an effective global climate change adaptation/mitigation framework. By committing to specific unilateral measures in the Accord, the issue is how can countries positively alter the incentives for other countries to commit to new measures – in essence hopefully propelling a snowballing like race to zero carbon on a wide scale?

To begin with, there is the issue of who the participants in global negotiations should be. Given that subnational groups are more likely to have the autonomy to commit resources in initiating unilateral measures, an open question is whether subnational groups, such as provinces, states, or territories, who can exercise such autonomy could be allowed to include their commitments directly in a global agreement post-Copenhagen.

Central to the model in the proceeding section is the idea of a global learning process, in which technology and innovation figure prominently. An alteration to the way technology transfer works on a global scale has already been proposed under paragraph 11 of the Copenhagen Accords and would aid in fostering learning. This proposal, which was presented by the G77 and China in Copenhagen, sets out a fast-track process for the diffusion of relevant technologies to either high emissions areas or those places where adaptation is already becoming a critical concern. As set out, this was to be governed by an Executive Body on Technology which would operate under the authority of the COP and operate using a new fund called the Multilateral Climate Technology Fund, largely financed by Annex II countries but supplemented by Annex I contributions, with the incentive being that contributions to the Fund would count towards a country's multilateral negotiation responsibilities[19]. The proposal sets out to accelerate the rate at which research and development on such technologies is conducted and to finance it through venture capital and aid in rapid commercialization and diffusion. There is an inherent

[19] A key advantage of this is that the amount of funding provided is not dependent on the price of carbon, allowing the flow of funds to be more stable than otherwise.

selection bias in this, since the Executive Body is selecting the innovations to go forward to commercialization, but this might be possibly minimized by the makeup of this group and the oversight of COP.

A key issue arising that previously arose with the Clean Development Mechanism (CDM) under the Kyoto Protocol, that is how to ensure "additionality". For example in the CDM case, firms would delay adoption of cost-effective low carbon technologies to benefit from CDM or use CDM to adopt technologies that they would have funded from capital markets or internal funds in any case(Olsen (2007), Wara and Victor (2008)). And so, missing in this proposal are what sort of conditions should be attached to payments to ensure "additionality". In the case of carbon mitigation technologies these conditions could be time bound carbon emission or carbon intensity targets, and this could be particularly useful in key sectors such as energy, infrastructure, transport and heavy industry.

The process described here may take time to play out so that the emission cuts required to stabilize global temperatures may not be delivered quickly. We envisage a process of technology diffusion that involves chains of innovations with new inventions based on other low carbon technologies. Such a process may require roughly 5-10 years to play out for each innovation, or more if the innovations become controversial in some way. Some of these new technologies will not be compatible with high carbon technologies and entire factories may need to be retooled (thus raising the adoption costs of the new technologies). Although innovation and subsequent transfer of new technologies is essential, emissions reduction may be achieved by ensuring the spread and adoption of *existing* low carbon technologies within and across countries. For example, households and firms within high income countries could be persuaded to insulate their houses or install solar panels by a combination of subsidies (or low cost loans), and by the extension of carbon markets to individual households and small firms/businesses.

To achieve the goal of ensuring that the pace of innovation in low carbon technologies is rapid, such a policy would likely have to be supplemented by other measures. If there is uncertainty over commitments to emission targets and carbon prices fluctuate over time, or are too low or if too many economic activities are excluded from emissions trading, there may be little or no impact on the behavior of firms and households. This may discourage innovation (costly investment in the production of new ideas) that lowers the relative cost of low carbon activities in the first place.

A missing element in this proposal is how it would interact with the currently existing intellectual property rights regime. What could be involved is a new global IP regime characterized by governments in countries developing publicly funded new technology that involves users in other countries at the development stage, paying a part (or whole) of the royalties paid by users in other countries for privately funded technology, joint ventures between relevant actors (either in the private and/or public sector) across national boundaries and lowering the cost of local use (and adaptation) of proprietary technologies by designing an appropriate international licensing system.

In order to qualify for funding under the proposed global IP regime countries would have to adopt specific commitments i.e. specific time-bound quantity targets like initially lowering carbon intensity followed by emission cuts, the adoption of low carbon technology (carbon capture and storage, solar and wind energy etc.) in important sectors such as energy, infrastructure, transport and industry. The funding of individual projects within a qualifying country could be decentralized so that royalties paid by users for privately funded technology originating elsewhere were refunded and the cost of local use (and adaptation) of such proprietary technologies subsidized. A portion of the funding could be reserved for research and development.

Innovations of the type needed in the key sectors mentioned above typically have to go through years, and sometimes decades, of testing and regulation approval before they can become commercially available. If this generally remains the case under the proposed Technology Mechanism, its effectiveness in mitigating carbon and other emissions in a timely manner may be questionable, and to a lesser extent, this is also true of technologies related more towards adaptation.

While not included in the proposal as it stands, the strength and structure of the links (positive spillovers) between countries in this process would be important in its success. For example, the US and the EU would be especially important because of their central role in the world economy and their generation of innovation and technology transfer. Others such as China and India would be important because of the size of their populations and potential for emissions mitigation. For example, existing "clean coal" power plants and carbon capture technologies can be developed and further refined in the US and EU with a subsequent transfer to China under the mechanism proposed for it to have a significant impact in cutting emissions. Other links may reflect structural similarities, land use patterns, existing patterns of carbon consumption, and of key features. Such a structure, if included in the proposal, would aid in the efficient distribution of funds by allowing them to be dispersed according to characteristics such as the degree of spillover by type of technology and by targeting countries that have the greatest potential to generate spillover effects[20]. Such a policy regime could also involve platforms where information relating to unilateral initiatives could be exchanged and is hence likely to involve subsidized monitoring.

Identifying, quantifying and strengthening spillovers will be key to the success of the proposed mechanism and could feasibly fit into the mandate of Strategic Planning Committee within the proposed Executive Body on Technology. This could be essential, as encouraging the type of technologies needed in generating positive spillovers across countries are both likely to be costly and trade-offs may become necessary.

In general, measures that reduce emissions inertia within a country and measures that strengthen the positive spillover effects across countries are both likely to be costly. With

[20]This would be due to specific characteristics such as size, influence, technological and innovation capabilities, the degree of similarity with other national economies such as location, patterns of land and energy use, dominance of key sectors, neighborhood effects etc.

resource constraints, there is likely to be a trade-off between the two such as subsidizing measures that improve the energy efficiency of domestic households or subsidizing low carbon technologies that reduce emissions in energy generation. The latter may have a higher potential to generate spillovers across countries while the former will have a bigger impact on reducing inertia within a country.

If cross-country spillovers occur on the level this proposal would need in order to be considered a success, an almost inevitable question arises of what this might do to trade flows. If this mechanism is to be a central feature of global climate change adaptation and mitigation efforts the implication is for a further integration between the trade and climate change regimes. This would have a number of benefits, not the least of which being the private sector incentive to be active on the climate change issue through the proliferation of innovations necessary for a global low carbon paradigm.

It also suggests an eventual enforcement mechanism in the form of trade sanctions or increased protectionism (or even the threat of such) against free riders or those who refuse to participate. Bundling trade and climate change negotiations together could ensure broader participation and compliance in climate change negotiations because the flow of immediate benefits associated with emission cuts (the benefits of lower trade barriers) could alter incentives for countries to participate in global negotiations. However, a necessary condition for such bundling to work is that the *threat* of increased protectionism by low carbon nations be renegotiation proof, a condition (i.e. increased protectionist tendencies) more likely to met by nations already undertaking unilateral initiatives as demonstrated by discussion of carbon based border adjustments to address issues of leakage.

5 Concluding Remarks

In this paper we discuss whether unilateral measures can act as an effective engine for reduction in carbon emissions and achieve the goal of limiting temperature rise to 2°C. Ultimately, this will depend on unilateral measures' relative effectiveness, their number, and their ability to create the synergies necessary to reduce the cost for other economies globally to follow suit and switch to low carbon via a process of global learning. For such a process to be successful, the post- Durban process going forward should attempt to build on both national and subnational efforts to promote the development and spread of effective unilateral action and encourage implementation of policy that strengthens the spillovers of such actions across nations, which is key to the social learning process we have described. Key for this process will be changes to the effective international intellectual property rights regime of the sort described in paragraph 11 of the Accord. A less restrictive regime is critical for allowing spillovers across nations to take place on a time scale, that would be meaningful for dealing with climate change according to the current science. Thus contrary to the popular view of the Copenhagen Accord being empty and a papered over agreement, in the context of the model described here, the Accord may have the potential to become a foundation for an effective post-Kyoto global climate change regime.

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