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A Full Participation Agreement On Global Emission Reduction Through Strategic Investments in R&D

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Abstract

If an emission reduction agreement with participation of all players is not enforceable because politicians are too myopic or not able to commit themselves to sustainable policies or costs of reducing emissions are too high, strategic investments in research and development (R&D) of green technology, for example sustainable drive-trains, can pave the way for a future treaty. Although no player will rationally reduce emissions on its own, investments in R&D by at least one player can change the strategic situation of negotiations to control emissions: Emission abatement costs will decrease so that a treaty with full participation can be achieved in future periods through time consistent sustainable policies.

Keywords: emissions; discount factor; commitment; endogenous technical change; repeated prisoner's dilemma

JEL: Q54; F53; O30; H41

1 Introduction

International cooperation to reduce environmental external effects, for example cross border emissions, often fails. Because no country has to participate and all countries can renegotiate their treaties at any times, especially if governments change due to regular elections, institutions that sustain international cooperation have to be both individually and collectively rational. Therefore, collective action through agreements to reduce cross border emissions has to be and has been analyzed by several game-theoretical

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contributions using dynamic models of international public goods provision (Carraro/Siniscalco 1993). Barrett (1999) uses a repeated N-player prisoner's dilemma game where each country can choose between participating on a global agreement, inducing the reduction of emissions, and rejecting the agreement. Because a deviating country is punished by all other countries, the number of participating countries has to be small if an agreement shall be enforced. However, if only a subset of countries participates in an agreement the environmental benefit of the agreement is at risk. Consider, for example, a single country reducing greenhouse gas emissions. If the world supply of fossil fuels remains fixed, a reduction in the demand for fossil fuels would merely lower the world price of carbon and provoke non-participating countries to consume what the participating countries have saved (Sinn 2008). The so-called "green paradox" sows seeds of doubt about the benefit of partial agreements.

Barrett (2002) demonstrates that many countries can participate in an agreement, but only if the abatement level of emission is lowered. To summarize, the approaches of Barrett (1999 and 2002) expose a trade-off between "narrow but deep" and "broad but shallow" treaties; however, society strives for "broad and deep".

Asheim et al. (2006) demonstrate that two treaties can encompass a larger number of parties than a single global treaty proposed by Barrett (1999), because under regional cooperation a deviator is punished by just a group of countries. Then the system with two agreements can Pareto dominate a regime based on one global treaty, meaning that the global reduction of emissions is greater under two agreements than under one single agreement. Nonetheless, even with two regional agreements, the number of participating countries is limited, leading again to the problem of the green paradox.

Froyn and Hovi (2008) offer a more optimistic view. They show that it may be possible to sustain full participation in one single agreement without watering down abatement levels. This can be achieved by limiting the number of countries that are permitted to punish a non-compliant country which has deviated from the agreement. Froyn and Hovi's (2008) findings can also be transferred to a model where countries can choose the level of abatement in every period, as Asheim and Holtsmark (2009) demonstrate. They show that a "broad and deep" agreement with full participation and abatement at an efficient level can always be achieved if the countries' common discount factor is sufficiently high.

However, as the experiences from Copenhagen show, global agreements about emission reduction currently seem to be not available. One reason may be that politicians place a high weight on present payoffs, but too less weight on payoffs in future legislative periods. Furthermore, abatement of emissions may be too expensive. In this paper, we will demonstrate a solution for this dilemma. If negotiations about the provision of an international public good like emission reduction fail because politicians are too myopic or abatement costs are too high, then investments in research and development (R&D) can pave the way for a future treaty. We will show that just one country can do the pioneer work to invest in green technology, so that emissions will effectively be slowed down. The investing country will not reduce emissions on its own, but will remove the debilitating strategic situation of emission reduction negotiations by bringing forward green technology. The improved technology will lead to a decrease of abatement costs. As soon as abatement costs are sufficiently reduced, there will be a future agreement with full participation.

2 The model

We consider a world consisting of N identical countries. In every period of the infinitely repeated game, each country has to decide whether to cooperate, i.e., to reduce emissions at cost $c > 0$, or to defect, i.e., not to reduce emissions. The mitigation of emissions is not limited to national borders, but is a global public good from which all countries can equally benefit. Let $k \leq N$ be the number of countries that participate in an agreement. Then, the periodic payoff for each of the k participating countries playing cooperate is $dk - c$, where $d > 0$ is a constant. Each of the $N - k$ non-participating countries playing defect receives dk. Future payoffs are discounted with a common discount factor $0 < \delta < 1$.

In the stage game, the provision of the global public good results in a prisoner's dilemma. No country will sign the agreement, because defect is a dominant strategy, $d(k-1) > dk - c \; \forall k$. This condition must also hold for the case of $k = 1$, therefore $c > d$ holds. It follows then that full participation cannot be a Nash equilibrium, because the assumption implies that $d(N-1) > dN - c$ for $k = N$. Furthermore, the outcome of the stage game is not Pareto efficient: Full participation will Pareto dominate zero participation, $dN - c > 0$. It follows that the number of countries must be sufficiently large, i.e., $N > c/d > 1$. This condition is assumed to be fulfilled.

3 A global agreement with immediate abatement

Following Froyn and Hovi (2008), a global agreement with full participation, i.e., $k = N$, can be accomplished by a strategy called Penance-m. Penance-m is characterized by three actions. First, each participating country plays cooperate as long as all other participating countries play cooperate as well. Second, if one country plays defect, m countries will punish the deviator by playing defect in the following period while the other $k - m$ countries will play cooperate. Third, if one of the m punishing countries deviates from playing defect in a period of punishment, it will be punished as well by m punishing countries playing defect in the following period. Countries are quick to forgive, therefore, the punishment lasts for one period only.

Penance-m must fulfill two conditions of equilibrium: subgame perfection and renegotiation-proofness. In the following, these two conditions are briefly introduced. However, see Froyn and Hovi (2008) for a more detailed discussion. Subgame perfection at time t is satisfied if no country has an incentive to deviate from Penance-m given any history, i.e., if every country abides by Penance-m after the previous periods $\tau = ..., t-2, t-1$. For a country playing cooperate, Penance-m is subgame perfect if

$$\sum_{\tau=t}^{\infty} \delta^{\tau}(dN-c) \geq \delta^{t} d(N-1) + \delta^{t+1}(d(N-m)-c) + \sum_{\tau=t+2}^{\infty} \delta^{\tau}(dN-c) \quad (1)$$

holds. For one of the m punishing countries playing defect, the condition of subgame perfection applies if

$$\begin{aligned} \delta^{t} d(N-m) + \sum_{\tau=t+1}^{\infty} \delta^{\tau}(dN-c) \geq \\ \delta^{t}(d(N-m+1)-c) + \delta^{t+1}(d(N-m)-c) + \sum_{\tau=t+2}^{\infty} \delta^{\tau}(dN-c). \end{aligned} \quad (2)$$

This condition holds for all k and for all δ because $d(N-m) > d(N-m+1)-c$ and $dN-c > d(N-m)-c$. Furthermore, subgame perfection requires that in a period of punishment all $N-m$ non-punishing countries play cooperate,

$$\begin{aligned} \delta^{t}(d(N-m)-c) + \sum_{\tau=t+1}^{\infty} \delta^{\tau}(dN-c) \geq \\ \delta^{t} d(N-m-1) + \delta^{t+1}(d(N-m)-c) + \sum_{\tau=t+2}^{\infty} \delta^{\tau}(dN-c). \end{aligned} \quad (3)$$

If condition (3) holds, (1) is satisfied as well. Solving (3) for the number of punishing countries results in a lower bound for m,

$$m \geq \underline{m} = \frac{c-d}{\delta d}. \quad (4)$$

The second requirement is that the strategy profile must be renegotiation-proof. Froyn and Hovi (2008) adopt weak renegotiation-proofness, which implies that the m punishing countries gain at least the same payoff with punishment as with renegotiation,

$$\sum_{\tau=t}^{\infty} \delta^{\tau}(dN-c) \leq \delta^{t} d(N-m) + \sum_{\tau=t+1}^{\infty} \delta^{\tau}(dN-c). \quad (5)$$

Renegotiation-proofness yields an upper bound for the number of punishing countries,

$$m \leq \bar{m} = \frac{c}{d}. \tag{6}$$

However, these conditions are not sufficient for an equilibrium. According to the Folk Theorem, all participating countries must attach sufficiently great importance to future payoffs.

Proposition 1. *Penance-m leads to a subgame perfect and weakly renegotiation-proof equilibrium if*

$$\frac{c-d}{\delta d} \leq m \leq \frac{c}{d} \tag{7}$$

and if the weight that countries place on future payoffs is sufficiently high:

$$\delta \geq \tilde{\delta} = 1 - \frac{d}{c}. \tag{8}$$

Proof. The lower bound $\underline{m}$ for the number of punishing countries follows from the subgame perfection requirement. There always exists a lower bound $\underline{m} > 0$ because, according to our assumption, $c > d$ holds. The upper bound $\bar{m}$ for the number of punishing countries results from the weak renegotiation-proofness requirement and is always lower than the number of participating countries N because, by assumption, $dN - c > 0$, and hence $N > c/d$.

For an equilibrium $\underline{m} \leq \bar{m}$ must hold. The upper bound $\bar{m}$ is independent of the discount factor. By contrast, the lower bound $\underline{m}$ decreases with an increasing discount factor δ. Therefore, the condition $\underline{m} \leq \bar{m}$ will only hold for discount factors that are high enough, i.e.,

$$\delta \geq \tilde{\delta} = 1 - \frac{d}{c}. \tag{9}$$

Because $c > d > 0$, it follows that $0 < d/c < 1$, and therefore $0 < \tilde{\delta} < 1$. □

Obviously, a global agreement with participation of all countries can only be achieved if abatement costs are not too high or/and the weight placed on future payoffs by the countries is not too low.

Aiming for re-election, politicians prefer local or national policy measures that cause immediate benefits to their voters, formalized through a low δ. To summarize condition (8), high emission abatement costs or myopia of politicians may foreclose a global agreement.

We offer a solution for this dilemma. In the next section, we show that a global agreement with full participation can be concluded if technical change lowers abatement costs over time. Hence, such an agreement may be achieved at a later date – as soon as the costs of reducing emissions have sufficiently declined.

4 A global agreement with future abatement

As from now, abatement costs c_t shall depend on the level of green technology y_t. The available technology is related to technical knowledge. The technology can be improved by investments in R&D, which will lead to a reduction in abatement costs. For example, the internal combustion engine, that creates large polluting emissions, is the drive-train used in almost all cars. As an alternative there are green technologies available, for example electric powered mobility. However, the user costs of sustainable drive-trains are still higher than the costs of the traditional internal combustion technology. Investments in R&D of sustainable drive-train technology can improve the cost efficiency of low-emission drive-trains and therefore reduce abatement costs of automobile traffic.

We consider the case in which no emission reduction agreement would be signed today, i.e., in which condition (8) is not satisfied. Abatement of emissions may either be too expensive in period $t = 0$, or politicians may be too myopic. In both cases, the crucial discount factor concerning the emission reduction contract exceeds the common discount factor of all countries,

$$\delta < \tilde{\delta}(t = 0) = 1 - d/c_0. \tag{10}$$

However, a global emission reduction agreement can be achieved in future periods, if one country does the pioneer work and invests in R&D. It is assumed that the investing country provides funds in the amount of I_t for R&D in the period t. For the purpose of simplification, the level of technology increases by a constant fraction $0 < \alpha < 1$ of investments I_t, where α reflects the efficiency of R&D with which the technology is improved. Because research is a timely process, the technological progress is bounded by $\hat{y}$, which is the maximum technological progress obtainable in one period of time. Then, $I = \hat{y}/\alpha$ is the level up to which investments in R&D are efficient. The increase in the technology level is thus given by

$$\Delta y_t = y_{t+1} - y_t = \min\{\alpha I_t, \hat{y}\}. \tag{11}$$

Provided that investment is efficient, i.e. $I_t \leq I$ for all t, the level of technology in period t equals

$$y_t = y_0 + \alpha \sum_{\tau=0}^{t-1} I_\tau \quad \text{with} \quad y_0 = 1. \tag{12}$$

It follows that a country has to invest I in each period to improve the technology as fast as possible. The improved technology leads to a decrease in abatement costs,

$$c_t = \frac{c_0 - d}{y_t} + d. \tag{13}$$

It is impossible to remove the prisoners dilemma of the stages by investment in technology, because $c_t > d$ applies in each future period. Defection, i.e., not participating in the emission reduction agreement, remains the dominant strategy in each of the stages. But even though investments in R&D are not a strategy to change the stage game, they may induce the countries to join the agreement in future periods. However, this requires one single country that leads the way.

Proposition 2. *For all δ, I, N and α there exists a finite $\tilde{t}$, such that the following strategies are an equilibrium, if the initial level of abatement costs is not too high: Exactly one country invests*

$$I_0 = \frac{(1-\delta)c_0 - d}{\alpha\delta d} - (\tilde{t}-1)I \tag{14}$$

in period $t = 0$ and $I_t = I$ from period $t = 1$ to $t = \tilde{t} - 1$, and all countries sign a global emission reduction treaty in $\tilde{t}$ that is based on Penance-m.

Proof. The pioneer aims to obtain the payoffs arising from the emission reduction agreement as soon as possible. Therefore, it will invest the maximum level I of investments, but stops investing as soon as the "breakthrough" technology level is reached, i.e., when condition (8) is satisfied. The "breakthrough" level shall be reached in $t = \tilde{t}$, so that an emission reduction agreement will come into effect in the same period. If the "breakthrough" technology would be exceeded in $\tilde{t}$, the pioneer would only invest the residual investment in one period. Due to discounting, the residual investment is made in period $t = 0$. Hence, the resulting technology at $t = \tilde{t}$ equals

$$y_{\tilde{t}} = 1 + \alpha(I_0 + (\tilde{t}-1)I). \tag{15}$$

According to (8), there will be a global emission reduction agreement at $t = \tilde{t}$, if abatement costs fulfill

$$c_{\tilde{t}} = \frac{c_0 - d}{1 + \alpha(I_0 + (\tilde{t}-1)I)} + d = \frac{d}{1-\delta}. \tag{16}$$

The residual investment I_0 thus equals

$$I_0 = \frac{(1-\delta)c_0 - d}{\alpha\delta d} - (\tilde{t}-1)I. \tag{17}$$

Because $I_0/I \leq 1$, the "breakthrough" technology is reached at

$$\tilde{t} = \left\lceil \frac{(1-\delta)c_0 - d}{\alpha\delta d I} \right\rceil. \tag{18}$$

where the brackets symbolize the ceiling function, which refers to the next largest natural number. At this point of time, condition (8) will be fulfilled, so that every country would sign a global emission reduction agreement based on Penance-m.

But the pioneer must have an incentive to invest: its investment strategy is optimal if

$$\sum_{\tau=0}^{\tilde{t}-1} \delta^\tau I_\tau \leq \sum_{\tau=\tilde{t}}^{\infty} \delta^\tau (dN - \frac{d}{1-\delta}), \tag{19}$$

i.e., if the present value of investments, which are optimally terminated at $\tilde{t}-1$, is at most the present value of payoffs from the induced global emission reduction agreement. Then, the point in time at which an agreement is reached is limited by an upper bound,

$$\tilde{t} \leq \frac{\ln((1-\delta)I_0 + \delta I) - \ln(dN - \frac{d}{(1-\delta)} + I)}{\ln \delta}. \tag{20}$$

Consequently, the effective date of the treaty must fulfill

$$\left\lceil \frac{(1-\delta)c_0 - d}{\alpha\delta d I} \right\rceil \leq \frac{\ln((1-\delta)I_0 + \delta I) - \ln(dN - \frac{d}{(1-\delta)} + I)}{\ln \delta}. \tag{21}$$

This is the case, if $c_0 \leq \hat{c}_0$ with

$$\hat{c}_0 = \left\lfloor \frac{\ln((1-\delta)I_0 + \delta I) - \ln(dN - \frac{d}{(1-\delta)} + I)}{\ln \delta} \right\rfloor \cdot \frac{\alpha\delta d I}{1-\delta} + \frac{d}{1-\delta}, \tag{22}$$

where the brackets symbolize the floor function, which refers to the next smallest natural number. Consequently, there is a global emission reduction agreement, if the initial level of abatement costs is not too high, as stated in the proposition.

There exists always a $\tilde{t} \geq 1$, because $(1-\delta)c_0 - d > 0$ holds by assumption (10), and therefore

$$\left\lceil \frac{(1-\delta)c_0 - d}{\alpha\delta d I} \right\rceil \geq 1 \tag{23}$$

is satisfied. The upper bound for the initial level of abatement costs fulfills the assumption that $\hat{c}_0 > d/(1-\delta)$, because $I_0 \leq I$, $(1-\delta)c_0 - d > 0$, $dN - c_0 > 0$ and therefore $\ln((1-\delta)I_0 + \delta I) < \ln(dN - d/(1-\delta) + I)$. $\square$

In period $\tilde{t}$, the "breakthrough" technology leads to a crucial discount factor $\tilde{\delta}$ that equals exactly the common discount factor of all countries, so that Penance-m becomes an applicable strategy for a global emission reduction agreement for the first time. All countries will sign the treaty in this period. The payoff for a cooperating country, provided that all other countries play cooperate as well, equals $dN - d/(1-\delta)$ for this and every following period. It is individually and collectively rational to play cooperate, because a deviating country would be punished on the basis of Penance-m.

5 Concluding Remarks

This paper offers a road map to limit cross border emissions effectively. Our analysis shows that strategic investments in R&D of green technology can pave the way for a future global agreement with the participation of all countries. These investments are no solution to the common good problem of emission reduction, but might change the strategic situation of environmental agreements. Although no country will rationally lead the way by reducing emissions on its own, one country can rationally lead the way by strategically investing in R&D, thereby enabling a global agreement with full participation.

While our model supports public investments in R&D, it does not support the popular claim that such policy results in future jobs or monopoly rents based on patents. For the conclusion of a global agreement with full participation, the newly developed green technology must be made available to all countries free of cost, at least during the agreement. Therefore, the pioneer that has developed the technology, cannot earn monopoly rents after $\tilde{t}$. New jobs may merely be created in R&D, but not necessarily in the production and distribution of the "breakthrough" technology afterwards.

A thorough analysis of the investment strategy shows that the investment in R&D is a chicken game between all countries. While it is optimal to invest if no other country invests, the payoffs are higher if another country bears the investment costs for the technology. However, one can imagine strategies where some countries share the burden. For example, in order to improve research efficiency and reduce development costs, the development of the new green technology could be accomplished by a cooperation of governments sharing the vision of a mankind of homo sustinens and/or of the countries who share green preferences and prefer sustainable economic activities.

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