The role of fixed cost in international environmental negotiations

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ABSTRACT. We investigate the relative efficiency of an agreement based on a uniform standard without transfers and one based on differentiated standards with transfers when strictly identical countries deal with transboundary pollution. We especially ask what role fixed cost plays. Two approaches are examined: the Nash bargaining solution, involving two countries, and the coalition formation framework, involving numerous countries and emphasizing self-enforcing agreements. In the former, in terms of welfare, strictly identical countries may wish to reduce their emissions in a non-uniform way under the differentiated agreement. For this result to hold, the fixed cost of investment in abatement technology must be sufficiently high. The nature of the threat point of negotiations, however, also plays a crucial role. As concerns global abatement, the two countries abate more under the uniform agreement than under the differentiated one. In terms of coalition formation when numerous countries are involved, a grand coalition could emerge under a differentiated agreement.

1. Introduction
A situation in which similar countries face the challenge of a transboundary pollution problem comes under study. Each country is both the cause...
and the victim of this pollution problem. The countries are identical in terms of abatement costs and their willingness to pay for cleaning up the environment they share. They are seeking an institutional arrangement in order to tackle this problem.

This institutional arrangement, in our case, is an International Environmental Agreement (IEA). Such an agreement is based on an abatement standard; this is defined as the reduction of current emissions in order to reach a percentage of the emissions of a base year. In this case, the countries could choose one standard from a set of two: either a uniform standard or a differentiated standard. The uniform standard means that the above-mentioned percentage would be the same for any country signing an agreement. The Montreal Protocol on Substances that Deplete the Ozone Layer fell into this category of agreements. It included a provision which specified a reduction of emissions of chlorofluorocarbons (CFCs) and halons by 20 per cent based on 1986 emission levels, to be accomplished by 1998 (Finus, 2001, chapter 11). The differentiated standard means that the percentages would be different according to the country. The Kyoto Protocol on Climate Change (1997) and the Oslo Protocol on Further Reduction of Sulphur Emissions (1994) are both examples of agreements with differentiated standards.

Within the context of a transboundary pollution problem across identical countries, we further define a uniform agreement to be the case where there is reciprocal action. This means that each country undertakes the same abatement effort, and any country involved pays for the fixed cost of investment in the abatement. This uniform abatement is a cost-effective solution given that the countries under study are identical. We call this undertaking an agreement based on a uniform standard without transfers or, in short, a uniform agreement. Since countries are identical, there is no need for a transfer payment scheme. We next define a differentiated agreement to be the case where there is unilateral action. This means that only some of the countries opt to make an abatement effort, and pay for the fixed cost, while any other countries compensate with transfers. We refer to this undertaking as an agreement based on differentiated standards with transfers or, in short, a differentiated agreement.

In this paper, we emphasize the role of environmental protection fixed costs, which are part and parcel of abatement technology, for the outcome of international environmental negotiations. The recent environmental cooperation around the regional pollution problem in the Mediterranean Sea can serve as an example. The Mediterranean Hot Spot Investment Programme (MeHSIP) and the Horizon 2020 initiative

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1 Another example is the Helsinki Protocol (1985), which suggested a reduction of sulphur dioxide from 1980 levels by 30 per cent by 1993.

2 Transfer payments are offered in order to increase participation in IEAs. Some examples of IEAs which include the possibility of transfers between countries are the Fur Seal Treaty (1911), the Montreal Protocol (1987) and the Stockholm Convention on Persistent Organic Pollutants (2001). See, respectively, Barrett (2003, p. 34), Barrett (2003, p. 346) and http://chm.pops.int/default.aspx for more details.
constitute the base of the European Union’s cooperation with the southern and eastern Mediterranean countries. The objective of MeHSIP is to abate 80 per cent of Mediterranean pollution by 2020. To help countries to undertake investment projects, the Programme foresees several financing mechanisms, both bilateral and multilateral. The report provided by the Programme Horizon 2020\(^3\) states that ‘Especially as concerns hazardous wastes, very little has been done so far in the MENA [Middle East and North Africa] countries to take care of this issue, the main reason for this being the high costs of the necessary investments e.g. incineration plants’ (p. 30). The high fixed installation cost of these plants represents some of the investment costs of the projects financed by MeHSIP. It is clear from this example that the abatement of hazardous wastes in these countries would not take place without MeHSIP’s funding. As this example, among others, illustrates, the level of fixed costs in abatement technology can play a role in the outcome of international environmental negotiations.

In this paper, we explore what role fixed cost plays. Given the agreements (uniform agreements and differentiated agreements) as we have defined them, more specifically, we investigate their relative efficiency. To conduct this analysis, we examine two different approaches. First, we adopt the Nash (1950) bargaining solution as an equilibrium of a negotiation game involving two countries. The threat point of negotiations is represented by Nash equilibrium. We will show that three types of Nash equilibria can emerge depending on the level of fixed cost. Secondly, we work within the coalition formation framework, involving thereby numerous countries and emphasizing self-enforcing agreements. We extend the model provided by Barrett (1994) by including fixed costs in the abatement technology. Here, we assume that signatories simply maximize their joint welfare, whereas non-signatories individually play Nash equilibrium strategies. We then ask if the differentiated agreement could lead to a larger number of signatories than the uniform one.

A considerable amount of literature focuses on the possible explanations for why uniform standards prevail in the presence of asymmetric agents.\(^4\) In general, unless the countries are similar, uniform standards are less flexible, and therefore less efficient than differentiated standards (Harstad, 2007, p. 2).\(^5\) However, studies show that in the case of IEAs, uniform standards are frequently the case (Hoel, 1991, p. 64; Harstad, 2007, p. 2). The following arguments are put forward to explain this frequency: the stability

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\(^3\) For more information, see http://ec.europa.eu/environment/enlarg/med/pdf/mehsip_report.pdf.

\(^4\) One can find in the literature several arguments explaining the use of uniform standards: the fairness argument (Welsch, 1992), the informational problems argument (Larson and Tobey, 1994; Harstad, 2007), the ‘focal point’ argument (Schelling, 1960), the agency problems argument (Boyer and Laffont, 1999).

\(^5\) If the countries have different marginal implementation costs, then uniform standards will increase the total cost of attaining a given environmental objective (Hoel, 1992, p. 142). In an earlier work, Kolstad (1987) showed that the efficiency losses associated with uniform environmental regulations increase when marginal benefit and cost functions become more steeply sloped.
of agreements argument (Finus and Rundshagen, 1998), the monetary transfers argument (Bayramoglu and Jacques, 2005) and the trade theory argument (Copeland and Taylor, 2005). Finus and Rundshagen (1998) show, in a coalition model, that for global pollutants, governments will decide on an agreement based on a uniform percentage reduction of emissions (known as the quota regime) rather than an agreement based on a uniform tax (known as the tax regime). In the tax regime, countries’ net benefits are unevenly distributed. In contrast, the quota regime distributes net benefits more in line with the countries’ characteristics, as abatement depends on initial emission levels. Bayramoglu and Jacques (2005) show, in a negotiation game involving two countries, the possible Pareto superiority of an agreement based on a uniform standard with transfers compared to an agreement based on differentiated standards. The intuition in that case was that if it is less expensive to make transfers payments across the countries in order to attract the country, which benefits less from global abatement but has lower abatement costs to abate, then it is in the interest of both of the countries to sign the uniform agreement. The argument behind the Copeland and Taylor (2005) trade model is that trade in goods can act as a substitute for trade in emission permits. Therefore, uniform emission reductions in a world with freely traded goods can be efficient, even if trade in permits is banned.

Our paper differs from the literature in that it focuses on a distinct issue. Our interest lies in the analysis of whether or not differentiated standards can be optimal for perfectly symmetric countries. McAusland (2005) uses, with a similar aim in mind, a political economy model to highlight the possible inefficiency of uniform environmental regulations for identical countries. McAusland shows that the harmonization of these regulations across jurisdictions could be negative for both the environment and global welfare, despite the countries being identical in all respects. This happens when politicians are captured by ‘dirty’ industries and if the local effects of damages are sufficiently large. The former condition results in weak environmental policy. The latter condition makes the policy harmonization less effective in internalizing pollution, and also leads to a lower harmonized environmental standard. These two effects are detrimental for the environment and in turn for global welfare. By taking into account fixed cost in abatement technology, in the Nash-bargaining setting for two countries, we show that the uniform agreement is positive for the global environment, but can be negative for the welfare of countries. In the coalition formation framework, involving numerous countries, the uniform agreement can lead to a lower coalition size than the differentiated one.

The paper is organized as follows. Section 2 presents the negotiation model based on the Nash-bargaining approach involving just two countries. The threat point of negotiations, the uniform agreement and the differentiated agreement are analysed respectively, with the comparison of the individual welfare of each country across the agreements. Section 3 provides an extension of the model within the coalition formation framework, involving thereby numerous countries and emphasizing self-enforcing agreements in the case of the two institutional arrangements
described earlier. Finally, in section 4 we discuss our findings in terms of
the level of fixed cost, individual welfare and self-enforcing agreement.

2. The model
The utility function of country \( i = 1, 2 \) is written as

\[
NB_i = B(a_i + a_{-i}) - C(a_i),
\]

(1)

where \( a_i \) is the individual abatement level of country \( i = 1, 2 \).

The benefits from global abatement are represented by the function
\( B(a_i + a_{-i}) \), assumed to be increasing and concave. For simplicity, we
assume that \( B(0) = 0 \).

The abatement costs are represented by the function \( C(a_i) = c_o + c(a_i) \),
when \( a_i \) is strictly positive. This function is composed of a fixed cost \( c_o \) and
a variable cost \( c(a_i) \). The variable cost function is assumed to be increasing
and convex. We assume that the total cost of a country is zero when it does
not abate, i.e., \( C(a_i) = 0 \) when \( a_i = 0 \) for \( i = 1, 2 \).

Throughout section 2, we will illustrate our theoretical results by an
example with quadratic benefit and cost functions. The chosen functional
forms are the following: \( B(x) = \alpha x - \frac{\beta}{2} x^2 \) with \( x < \frac{\alpha}{\beta} \), and \( c(x) = \frac{\gamma}{2} x^2 \).
Parameters \( \alpha, \beta \) and \( \gamma \) are assumed to be strictly positive.

In this paper, we compare the abatement and welfare levels under
the agreement based on a uniform standard without transfers, hereafter
denoted as \( U \), and the agreement based on differentiated standards with
transfers, hereafter denoted as \( DT \). Agreement \( U \) implies the same level of
abatement for the countries \( (a_i = a_{-i}) \), whereas agreement \( DT \) allows differ-
ent levels of abatement \( (a_i = 0 \text{ and } a_{-i} \neq 0 \text{ or } a_i \neq 0 \text{ and } a_{-i} = 0) \). Moreover,
under this agreement, the country which undertakes an abatement effort
and pays for the fixed cost of investment receives transfer payments from
the other country \( (t > 0) \). A question arises: is there a threshold level of
fixed cost above which the DT agreement is better for each country than
the U agreement? We shall show that it is not obviously so.

Before analysing the outcome of the negotiations, we first study the non-
cooperative equilibrium of the game, which constitutes the threat point in
the negotiations.

2.1. Non-cooperative equilibria
The non-cooperative game is represented here by Nash equilibrium. The
objective of each country is to maximize its utility function by taking the
abatement level of the other country as given

\[
\max_{a_i} NB_i = \max_{a_i} [B(a_i + a_{-i}) - c_o - c(a_i)].
\]

(2)

We will show that two threshold levels of fixed cost \( c_{o1} \) and \( c_{o2} \) define
three types of Nash equilibria:

1. For \( c_o < c_{o1} \): each country abates (Type 1 symmetric Nash equilibrium).
2. For \( c_{o1} < c_o < c_{o2} \): only one country (say country 1) abates (Type 2
asymmetric Nash equilibrium).
3. For $c_o > c_{o2}$: no country abates (Type 3 symmetric Nash equilibrium).

We now define the levels of abatement and the above-mentioned threshold levels of fixed cost which limit the range of each type of Nash equilibrium.

**Lemma 1:** Let $\hat{a}$ be the abatement of each country at Type 1 symmetric Nash equilibrium. It is characterized in the following way: $B'(2\hat{a}) = c'(\hat{a})$.

Let $\hat{a}$ be the abatement of country 1 at Type 2 asymmetric Nash equilibrium. It is characterized in the following way: $B'(\hat{a}) = c'(\hat{a})$.

**Proof:** See proof of Proposition 1.

**Lemma 2:** Let $c_{o1}$ be the threshold level of fixed cost below which each country abates at Type 1 symmetric Nash equilibrium: $c_{o1}$ is equal to $B(2\hat{a}) - c(\hat{a}) - B(\hat{a})$.

Let $c_{o2}$ be the threshold level of fixed cost above which no country abates at Type 3 symmetric Nash equilibrium: $c_{o2}$ is equal to $B(\hat{a}) - c(\hat{a})$.

**Proof:** See proof of Proposition 1.

**Lemma 3:** $c_{o1} < c_{o2}$.

**Proof:** See online Appendix available at http://journals.cambridge.org/EDE.

Proposition 1 presents the general conditions under which the three Nash equilibria exist.

**Proposition 1:** If $0 < c_o < c_{o1}$, then the equilibrium is a Type 1 symmetric Nash equilibrium with the following levels of utility for each country,

$$NB^*_1 = NB^*_2 = B(2\hat{a}) - c_o - c(\hat{a}).$$

If $c_{o1} < c_o < c_{o2}$, then the equilibrium is a Type 2 asymmetric Nash equilibrium with the following levels of utility for the countries,

$$NB^*_1 = B(\hat{a}) - c_o - c(\hat{a}); \quad NB^*_2 = B(\hat{a}).$$

If $c_o > c_{o2}$, then the equilibrium is a Type 3 symmetric Nash equilibrium with the following levels of utility for each country,

$$NB^*_1 = NB^*_2 = 0.$$

**Proof:** See online Appendix available at http://journals.cambridge.org/EDE.

**Remark 1:** If $c_{o1} > 0$ does not hold, then Type 1 symmetric Nash equilibrium will not exist. In this case, only Type 2 asymmetric Nash equilibrium and Type 3 symmetric Nash equilibrium will prevail.
We will illustrate the results of this section using the above-mentioned quadratic example.

**Example:** We obtain: $\hat{a} = \frac{\alpha}{\gamma + 2\beta}$, $\hat{\alpha} = \frac{\alpha}{\gamma + 2\beta}$, $c_{o1} = \frac{\alpha^2(4\beta + 3\gamma)}{2(\gamma + 2\beta)^2} - \left(\frac{\alpha^2(2\gamma + \beta)}{2(\gamma + \beta)^2}\right)$, $c_{o2} = \frac{\alpha^2}{2(\gamma + \beta)}$, $B(\hat{a}) = \frac{\alpha^2(2\gamma + \beta)}{2(\gamma + \beta)^2}$, $B(2\hat{a}) - c(\hat{a}) = \frac{\alpha^2(4\beta + 3\gamma)}{2(\gamma + 2\beta)^2}$. It is clear that $c_{o1} < c_{o2}$ because $[4\gamma^2\beta + 15\gamma\beta^2 + 4\beta^3] > 0$. Assumption $c_{o1} > 0$ holds if and only if $\gamma(\gamma + \beta) > \beta^2$.

In the following section, we analyse the outcomes of negotiations on agreements U and DT. Since the countries are identical, we can assume that they have the same negotiation power. Therefore, our focus is on the simple Nash bargaining solution with identical negotiation powers.

### 2.2. Cooperation: the agreement on a uniform standard without transfers and the agreement on differentiated standards with transfers

Depending on the type of Nash equilibrium (1, 2 or 3), we determine the payoffs of the countries for each agreement: agreement U and agreement DT. We then show that for Type 1 and Type 2 Nash equilibria, at least one of the two agreements dominates the Nash equilibrium. Moreover, for each Nash equilibrium, we highlight the threshold level of fixed cost above which agreement DT outperforms, in terms of welfare, agreement U. It is worthwhile noting that these thresholds do not necessarily belong to the range of the related Nash equilibrium. This gives rise to different configurations of equilibrium that we highlight later (proposition 5). As concerns Type 3 symmetric Nash equilibrium, we show that there is a threshold level of fixed cost above which none of the two agreements leads to gains in cooperation. Finally, we compare the levels of global abatement across the agreements U and DT (proposition 6).

Here we define the two agreements (definition 1), we characterize the associated levels of abatement (lemma 4) and the thresholds levels of fixed cost (propositions 2, 3 and 4). We analytically compare these levels of fixed costs (lemma 5). Subsequently, we illustrate these results by an example with quadratic benefit and cost functions.

**Definition 1:** The objective of the countries is to maximize the following Nash function with respect to $a_1, a_2$ and $t$: $N(a_1, a_2, t) = [B(a_1 + a_2) - c_o - c(a_1) + t - NB_1^*] \times [B(a_1 + a_2) - c_o - c(a_2) - t - NB_2^*]$, where $NB_1^*$ and $NB_2^*$ are the respective payoffs of the countries at the threat point.

The U agreement results from this maximization problem under the following constraints: $a_1 = a_2 = \bar{a}$ and $t = 0$.

The DT agreement results from the same maximization problem under the following constraints: $a_1 \neq 0, a_2 = 0$ and $t > 0$.

**Remark 2:** As concerns agreement DT, it is equivalent to define it in the following way: $a_1 = 0, a_2 \neq 0$ and $t < 0$. We arbitrarily assume here that the country which undertakes an abatement effort is country 1.
Lemma 4: Let $\bar{\pi}$ be the uniform abatement of the countries under agreement $U$. It is characterized in the following way: $2B'(2\bar{\pi}) = c'(\bar{\pi})$.

Let $a_1$ be the abatement of country 1 under agreement $DT$. It is characterized in the following way: $2B'(a_1) = c'(a_1)$.

As concerns agreement $DT$, the level of transfers from country 2 to country 1, given Types 1, 2 and 3 Nash equilibria, are respectively equal to $(\frac{c(a_1) + c_o}{2})$, $(\frac{c(a_1) - c(\hat{a})}{2})$, and $(\frac{c(a_1) + c_o}{2})$.

Proof: See online Appendix available at http://journals.cambridge.org/EDE.

Proposition 2: If the threat point of negotiations is Type 1 Nash equilibrium, then agreement $DT$ is better for each country, in terms of welfare, than agreement $U$, if the fixed cost is higher than $c_o = 2(B(2\bar{\pi}) - c(\bar{\pi})) - (2\bar{B}(a_1) - c(a_1))$.

Agreement $U$ always dominates, in a Pareto sense, Type 1 Nash equilibrium.

Proof: See online Appendix.

The first part of this proposition is quite intuitive: when the fixed cost of investment in abatement technology is sufficiently high, it is better that only one of the countries abates. As we will see later on, the mere presence of a high level of fixed cost is, however, not enough for the superiority of agreement $DT$ over agreement $U$.

Proposition 3: If the threat point of negotiations is Type 2 Nash equilibrium, then agreement $DT$ is better for each country, in terms of welfare, than agreement $U$, if the fixed cost is higher than $c_o = B(2\bar{\pi}) - c(\bar{\pi}) - B(a_1) - \frac{[c(\hat{a}) - c(a_1)]}{2}$.

Agreement $DT$ always dominates, in a Pareto sense, Type 2 Nash equilibrium.

Proof: See online Appendix.

The first part of this proposition says the following: when the fixed cost of abatement technology is lower than $c_o$, but higher than $c_{o1}$, then it is better to negotiate an agreement based on mutual abatement ($U$ agreement), whereas only country 1 abates at the non-cooperation. This result is explained by the fact that, at the cooperation, global abatement benefits are sufficiently high that they counterbalance the payment of abatement costs.

Proposition 4: If the threat point of negotiations is Type 3 Nash equilibrium, then agreement $DT$ is better for each country, in terms of welfare, than agreement $U$, if the fixed cost is higher than $c_o$.

Agreement $U$ dominates, in a Pareto sense, Type 3 Nash equilibrium if and only if the fixed cost is lower than $c_{oU} = B(2\bar{\pi}) - c(\bar{\pi})$.

Agreement $DT$ dominates, in a Pareto sense, Type 3 Nash equilibrium if and only if the fixed cost is lower than $c_{oDT} = 2B(a_1) - c(a_1)$.

Proof: See online Appendix.

First, when the threat point of negotiations is represented by Type 1 Nash equilibrium, i.e., when the countries abate at the non-cooperative
equilibrium, then agreement U always leads to gains to cooperation. Secondly, when the threat point of negotiations is represented by Type 2 Nash equilibrium, i.e., when only country 1 abates at the non-cooperative equilibrium, then agreement DT always improves upon the non-cooperative outcome. Hence, in these two cases there exist at least a cooperative agreement (agreement U or DT) which leads to gains in cooperation no matter the level of the fixed cost. However, when the threat point of negotiations is represented by Type 3 Nash equilibrium, i.e., when no country undertakes abatement activities at the non-cooperative equilibrium, the level of fixed cost comes into play. In this case, agreement U (resp. agreement DT) improves upon the non-cooperative outcome if \( c_o < c_oU \) (resp. \( c_o < c_oDT \)). In the opposite case, there is no gain in cooperation.

**Lemma 5:** The threshold levels of fixed cost can be ranked in the following way:

1. \( c_o2 < c_oU < c_oDT \).
2. \( \overline{c_o} < c_oU \).
3. If \( \overline{c_o} > 0 \), then \( \overline{c_o} < \overline{c_o} \).

Proof: See online Appendix.

**Example:** With the above example with quadratic benefit and cost functions, we obtain:

\[
\alpha = 2\alpha; \quad a_1 = \frac{2\alpha}{\gamma + 2\beta}; \quad c_oU = \frac{2\alpha^2}{\gamma + 2\beta}; \quad c_oDT = \frac{2\alpha^2}{\gamma + 2\beta}; \quad \overline{c_o} = 2c_oU - c_oDT = \frac{4\alpha^2}{\gamma + 4\beta} - \frac{2\alpha^2}{\gamma + 2\beta} \quad \overline{c_o} = \frac{\alpha}{2} \left( \frac{\alpha}{\gamma + \beta} \right)^2 = \frac{2\alpha^2}{\gamma + 2\beta} - \frac{\alpha^2}{\gamma + 2\beta} = \frac{\gamma}{4} \left( \frac{\alpha}{\gamma + \beta} \right)^2.
\]

We then have:

1. \( c_o2 = \frac{\alpha^2}{2(\gamma + \beta)} < c_oU = \frac{2\alpha^2}{\gamma + 4\beta} < c_oDT = \frac{2\alpha^2}{\gamma + 2\beta} \).
2. \( \overline{c_o} = \frac{4\alpha^2}{\gamma + 4\beta} - \frac{2\alpha^2}{\gamma + 2\beta} < c_oU = \frac{2\alpha^2}{\gamma + 2\beta} \). Here, \( \overline{c_o} \) is not negative no matter the value of the parameters.
3. \( \overline{c_o} = \frac{4\alpha^2}{\gamma + 4\beta} - \frac{2\alpha^2}{\gamma + 2\beta} > 0 \) and \( \overline{c_o} = \frac{\gamma}{2} \left( \frac{\alpha}{\gamma + \beta} \right)^2 > 0 \). Recall that \( \overline{c_o} = \frac{1}{2} (\overline{c_o} - c(\overline{\alpha})) \), then \( \overline{c_o} < \overline{c_o} \).

Proposition 5 summarizes the three configurations in relation to the benefit function \( B(.) \) and to the variable abatement cost function \( c(.) \). Indeed, the threshold levels of fixed cost depend on functions \( B(.) \) and \( c(.) \).

**Proposition 5:** (1) If \( \overline{c_o} < c_o1 < \overline{c_o} < c_o2 \), as \( c_o \) increases, then the U agreement is first negotiated for a fixed cost lower than \( c_o1 \), afterwards the DT agreement is negotiated until \( c_oDT \) is reached. If the fixed cost exceeds \( c_oDT \), Type 3 Nash equilibrium prevails (absence of abatement).

(2) If \( c_o1 < \overline{c_o} < c_o2 < \overline{c_o} < c_oU \), as \( c_o \) increases, then the U agreement is first negotiated for a fixed cost lower than \( \overline{c_o} \), afterwards the DT agreement is negotiated until \( c_o2 \), the U agreement is again negotiated when \( c_o2 < c_o < \overline{c_o} \), the

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6 Two more cases can theoretically arise, but we have not found the numerical examples to illustrate them. They are qualitatively similar to cases 1 and 3.
DT agreement again comes into force when $c_o < c_{oDT}$. Finally, if the fixed cost exceeds $c_{oDT}$, Type 3 Nash equilibrium prevails (absence of abatement).

(3) If $c_{o2} < \bar{c}_o < c_{oU}$, as $c_o$ increases, then the U agreement is first negotiated for a fixed cost lower than $\bar{c}_o$, afterwards the DT agreement is negotiated until $c_{oDT}$ is reached. If the fixed cost exceeds $c_{oDT}$, Type 3 Nash equilibrium prevails (absence of abatement).

We illustrate the three cases of proposition 5 in tables A1 and A2 (available in the online Appendix at http://journals.cambridge.org/EDE) by using the above example with quadratic benefit and cost functions. Our findings as regards proposition 5(1) and 5(3) can be summarized as follows. The U agreement is preferred by the countries to agreement DT for a sufficiently low level of fixed cost of investment. Conversely, when the fixed cost exceeds a threshold level $[c_o > c_{o1}$ in (1) and $c_o > \bar{c}_o$ in (3)], the countries are better off under agreement DT. These findings illustrate that strictly identical countries can have an interest in reducing their emissions differently, and not in a uniform way. This result can be explained by the assumption of fixed cost in the abatement technology which implies a local non-convexity of the abatement cost function. Identical countries could be better off by signing an agreement based on differentiated standards with transfers in order to take advantage of local increasing returns to scale in abatement activities. In this case, one of the countries abates for both, and pays for the fixed cost of investment. In return, it is compensated by monetary transfers for this effort. We have shown that in such a case the level of fixed cost must be sufficiently high.

A new result emerges for a different configuration given by proposition 5(2). In this case, the preference of countries over the two alternative agreements changes as the level of fixed cost increases. The optimality of the U agreement and the DT agreement are occurring by turns. The U agreement which is first negotiated for a low level of fixed cost ($c_o < \bar{c}_o$) could also be preferred by the countries for a higher level of fixed cost ($c_{o2} < c_o < \bar{c}_o$). The DT agreement which is first agreed on for a medium level of fixed cost ($\bar{c}_o < c_o < c_{o2}$) could also be negotiated for a high level of fixed cost ($\bar{c}_o < c_o < c_{oDT}$). The explanation of this result is as follows. As the level of fixed cost increases, the threat point of negotiations changes. As we have already seen, for each threat point, there exists a threshold level of fixed cost under which it is better to negotiate a U agreement and above which it is better to negotiate a DT agreement. Consequently, as $c_o$ increases, it is possible that the type of the best agreement changes because the threat point changes. If we do not observe this alternation (as in cases 1 and 3), it is because for a given threat point, this threshold level of fixed cost (under which it is better to negotiate the U agreement, and above which it is better to negotiate the DT agreement) does not belong to the range of that threat point. In this case, the intuitive result prevails: as $c_o$ increases from 0, the best agreement is first the U agreement, and above the threshold level of fixed cost, the best agreement is the DT agreement.

The difference in these three configurations is due to the forms of the benefit function $B(.)$ and the variable abatement cost function $c(.)$, which modify the ranking of the threshold levels of fixed cost. In all three
configurations, the countries prefer to not cooperate for a very high level of fixed cost \( c_o > c_{oDT} \). In such a situation, none of the countries abates because it is too costly (Type 3 Nash equilibrium).

We can now compare the levels of abatement of different institutional arrangements.

**Proposition 6:** Given the assumptions on the concavity of the benefit function from global abatement \( B(.) \) and the convexity of the variable abatement cost function \( c(.) \), we have the following ranking of the abatement levels: \( 2\hat{a} > \hat{a} \) and \( 2\hat{a} > a_1 \).

Proof: See online Appendix.

Proposition 6 states that the total abatement is higher when both countries make an effort to abate (the case of a uniform standard without transfers) rather than when only one country abates and the other country compensates it for this effort (the case of differentiated standards with transfers). This also holds for the non-cooperative equilibria. To be more specific, the level of total abatement is higher when the two countries abate (Type 1 Nash equilibrium) than when only one of the countries abates (Type 2 Nash equilibrium). This is due to the concavity of the benefit function and to the convexity of the abatement cost function. Nevertheless, when we take into account the level of individual welfare, which is influenced by the level of fixed cost, we have seen that it could be better that only one of the countries undertakes an abatement effort.

In the next section, we tackle the issue of fixed costs in terms of self-enforcing agreements for numerous countries. The theoretical framework put forward by Barrett (1994) is adopted.

3. Extension: stability of agreements

We posit the context of \( i = 1, 2, \ldots, N \) identical countries facing a transboundary pollution problem, as is the case when the issue is the climate change or the ozone layer. We will compare the number of countries that join a cooperative agreement for the given two types of agreements: the uniform and the differentiated ones. We are guided by the literature on the internal and external stability of IEAs (Carraro and Siniscalco, 1993; Barrett, 1994). The majority of the models adopting this approach come to the conclusion that the size of the stable coalition is very small, unless punishment strategies in a repeated game framework are taken into account. As de Zeeuw (2008) stresses, trigger mechanisms highlighted in repeated games are similar to the \( \gamma \)-core concept used in cooperative game theory to analyse the stability of the grand coalition (Chander and Tulkens, 1995).

We assume that the coalition of signatory countries plays Nash equilibrium strategies with the individual outsiders (non-signatories). The

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7 This concept of stability of coalitions is taken from the literature on cartel stability (d’Aspremont et al., 1983). This concept has some drawbacks. First, it excludes group deviations. This issue is tackled in Finus and Rundshagen (2003). Secondly, it assumes that a given country believes that other countries do not react to a change in its behaviour. This last point was challenged by the concept of farsighted stability (for a recent application, see de Zeeuw, 2008).
outsiders are also assumed to have Nash equilibrium strategies between them (symmetric Nash equilibrium). We adopt one of the models in Barrett (1994) with linear benefit and quadratic cost functions, for which it is possible to obtain analytical results. 8 We also assume that there is a fixed cost in abatement technology. When a country does not abate, its abatement cost is assumed to be null.

For agreement DT, we posit the existence of an arrangement between \((p)\) signatory countries in the coalition which abate \((a_s > 0)\) and pay a fixed cost \(c_o\), and \((m)\) signatory countries in the coalition which do not abate, but pay a transfer \((t)\) to other coalition members. Then the number of non-signatories is \(N – (p + m)\). Their individual abatement level is represented by \((a_n)\). The agreement U is the case with \(m = 0\) and \(t = 0\): all the coalition members abate and pay the fixed cost, so there is no need for a transfer scheme. The calculations for agreement U are identical to the below calculations of agreement DT by putting \(m = 0\).

Each non-signatory maximizes \textit{ex ante} its own utility by taking the abatement levels of all other countries as given. The program of a non-signatory is written as follows:

\[
\max_{a_n} \left\{ NB_n = w \left( pa_s + \sum_{i=p+m+1}^{i=N} a_n^i \right) - c_o - \frac{ca_n^2}{2} \right\},
\]

(3)

where \(w\) represents the slope of each country’s damage curve and \(c\) represents the slope of each country’s marginal abatement cost curve. 9 We obtain \(a_n^i = a_n = \frac{w}{c}\). We assume that an outsider country will abate if its utility when it abates is higher or equal to that when it does not abate. This condition reduces to the following: \(w \geq \sqrt{2c_o c}\). 10 This condition states that the outsider abates if the marginal benefit from abatement is sufficiently high, or, in other words, if the fixed cost of abatement is sufficiently low.

At equilibrium, the utility level of a coalition member which abates and receives a transfer payment (recipient) from other coalition members is written in the following way:

\[
NB_s = w(pa_s + (N – (m + p))a_n) - c_o - \frac{ca_s^2}{2} + \frac{mt}{p}.
\]

The expression of transfers \((\frac{m}{p}t)\) comes from the fact that \(m\) countries make a transfer payment \(t\) and these total payments are equally

8 Barrett (1994) assumes that a Stackelberg game is played between the coalition of signatory countries, which moves first, and the outsiders (followers). In the case of a constant marginal benefit function, this assumption yields the same outcomes as those under the assumption of Nash equilibrium strategies (Rubio and Casino, 2005, p. 90, footnote 2).

9 A linear damage function implies that every unit of pollution has a similar marginal effect on the environment. As Kolstad (2000, p. 187) stresses, CO2 emissions could be assumed to exhibit such constant marginal damage. In line with the literature, we assume that returns to scale in abatement technology are diminishing.

10 Proof: The utility level of an outsider when it abates is the following: \(NB_{n1} = w(pa_s + \sum_{n=p+m+1}^{n=N} a_n) - c_o - \frac{ca_n^2}{2}\). Its utility when it does not abate is: \(NB_{n2} = w(pa_s + \sum_{n=p+m+2}^{n=N} a_n)\). It is easy to check that \(NB_{n1} \geq NB_{n2}\) when \(w \geq \sqrt{2c_o c}\).
shared across \( p \) recipient countries. At equilibrium, the utility level of a coalition member which does not abate but does make a transfer payment (donor) to other coalition members, is written in the following way: \( NB_s = w(p a_s + (N - (m + p))a_n) - t \). We assume that the level of transfers is such that the gains to cooperation are identical across the two groups of signatories.\(^{11}\) This gives us the following level of transfers: \( t = \frac{p}{p+m}[c_o + \frac{c a_s^2}{2}] \). Subsequently, the utility level of each coalition member is the following:

\[
NB_s = w(p a_s + (N - (p + m))a_n) - \frac{p}{p+m} \left[ c_o + \frac{ca_s^2}{2} \right].
\]

As concerns agreement DT, we first determine the abatement levels of the \( p \) recipient countries in a coalition of \((p + m)\) members. The regulator of the coalition aims to maximize the joint welfare of all its members:

\[
\max_{a_s} \left\{ (p + m) \left[ w \left( p a_s + \sum_{n=p+m+1}^{N} a_n \right) \right] - p \left[ c_o + \frac{ca_s^2}{2} \right] \right\}.
\]

The transfer disappears in the sum. The optimum is achieved for:

\[ a_s |_{p+m} = \frac{(p+m)w}{c}. \]

The problem is now to determine \((p + m)^*\), the number of countries that sign the IEA when the conditions for the internal stability and the external stability of the coalition are met.

**Definition 2:** An IEA consisting of \((p + m)\) signatories must satisfy the two conditions:

- **internal stability:** \( NB_n(p + m - 1) \leq NB_s(p + m) \)
- **external stability:** \( NB_n(p + m) \geq NB_s(p + m + 1) \)

The internal stability guarantees that a signatory country does not have an incentive to leave the coalition, and the external stability ensures that an outsider country does not have an incentive to join the coalition.

**Proposition 7:** If non-signatories abate \((w \geq \sqrt{2c_o c})\):

1. As concerns agreement U \((m = 0)\), the stable number of countries in the coalition is equal to 2 when the total number of countries is 2, and is equal to 3 when the total number of countries is at least 3.
2. As concerns agreement DT \((m \geq 1)\), the number of signatories which abate is 2 \((p = 2)\) and the number of signatories which make a transfer payment is any positive number \(m \) \((m \geq 1)\) when the total number of countries is at least 3. The stable number of countries in the coalition is thus at least 3, providing the possibility for a grand coalition.

\(^{11}\) For equity reasons, we assume identical transfers for all members. We could also consider more complex transfer schemes between donor and recipient countries.
When the fixed cost of abatement is sufficiently low \((w \geq \sqrt{2c_o c})\), our findings as regards proposition 7(1) replicate the result of Barrett (1994) with linear benefit and quadratic cost functions. In fact, the agreement that Barrett (1994) takes into account is identical to the U agreement as it is defined in this paper. Here, the existence of a fixed cost in abatement technology is taken into account compared to the model of Barrett (1994). When the fixed cost is sufficiently low, as in this case, the countries even abate in the non-cooperative situation. Therefore, they pay the fixed cost both in cooperation and in non-cooperation. We show, as Barrett (1994) does, that the U agreement is not able to sustain more than two or three signatory countries. In contrast, under the same condition for the level of fixed cost, agreement DT is able to generate a stable coalition if there is precisely two coalition members that abate and pay the fixed cost, with at least one coalition member that finances their abatement efforts. The higher the number of donor countries in the coalition, the larger the size of the stable coalition. It follows that a grand coalition can emerge in the case of a differentiated agreement.

Given the coalition size for each agreement, we now compare the levels of individual payoff, individual abatement, and global abatement across the U and DT agreements.

**Proposition 8:** If non-signatories abate \((w \geq \sqrt{2c_o c})\) and if the total number of countries is at least 3 \((N \geq 3)\):

1. The individual payoff under agreement U (with a coalition size of 3) is higher than that under agreement DT (with a coalition size of \(2 + m\), with \(m \geq 1\)).
2. The individual abatement under agreement DT is higher than or equal to that under agreement U.
3. The global abatement under agreement DT is higher than that under agreement U, if the number of countries which make a transfer payment in agreement DT is at least 5.

Proof: See online Appendix.

When the fixed cost of abatement is sufficiently low, \((w \geq \sqrt{2c_o c})\), we know that the number of countries which abate is 3 for agreement U, and it is equal to 2 for agreement DT. As proposition 8(2) shows, the higher the number of countries which abate, the lower the level of individual abatement. This leads to the reduction of individual abatement costs in agreement U. This reduction in costs is able to offset the lower level of benefits from global abatement, the latter being true for \(m \geq 5\) [proposition 8(3)]. Therefore, each signatory country is better off under agreement U than under agreement DT [proposition 8(1)]. The global payoff associated with an agreement is defined as the sum of the payoff of signatories and the payoff of non-signatories. The comparison of the global payoff under agreements U and DT is ambiguous. It depends on the values of the total number of countries, \(N\), and the number of donor countries in agreement DT, \(m\).
Proposition 9: If non-signatories do not abate \( (w < \sqrt{2c_0c}) \):

1. As concerns agreement U \((m = 0)\), when the total number of countries is at least 2, then the stable number of countries in the coalition is equal to 2 if \( 2 \geq \frac{2c_0c}{w^2} \), zero if not.
2. As concerns agreement DT \((m \geq 1)\), when the total number of countries is at least 2, then the number of signatories which abate is 1 \((p = 1)\) and the number of signatories which make a transfer payment is 1 \((m = 1)\) if \( 3 \leq \frac{2c_0c}{w^2} \leq 4 \), when the total number of countries is at least 3, then the number of signatories which abate is 2 \((p = 2)\) and the number of signatories which make a transfer payment must satisfy \( m + 2 \geq \frac{2c_0c}{w^2} \).

Proof: See online Appendix.

When the fixed cost of abatement is sufficiently high \((w < \sqrt{2c_0c})\), the U agreement is not able to sustain more than two signatory countries, no matter the total number of countries affected by the environmental problem. In contrast, under the same condition for the level of fixed cost, agreement DT is able to generate a stable coalition of at least three countries, if the total number of countries is sufficiently high. Again, the higher the number of donor countries in the coalition, the larger the size of the stable coalition. The high level of fixed costs requires, however, more donor countries in this case. If there was no possibility of transfer payments between countries, the stable coalition would contain only two signatories (this falls into the case of agreement U).

Proposition 10: If non-signatories do not abate \( (w < \sqrt{2c_0c}) \) and if the total number of countries is 2 \((N = 2)\):

1. With a coalition size of 2, the individual payoff under agreement U is higher than that under agreement DT.
2. The global payoff under agreement U is higher than that under agreement DT if \( 2 \geq \frac{c_0c}{w^2} \).
3. The individual abatement under agreement DT is equal to that under agreement U.
4. The global abatement under agreement U is higher than that under agreement DT.

Proof: See online Appendix.

When the fixed cost is sufficiently high \((w < \sqrt{2c_0c})\) and the total number of countries is 2, we know that the number of countries which abate is 2 for agreement U, and 1 for agreement DT. Proposition 10(3) shows that, under agreement DT, one of the countries makes the abatement equal to the sum of the abatement levels of countries under agreement U. Since the global abatement is higher for agreement U [proposition 10(4)], this leads to higher benefits from global abatement under this agreement. Indeed, this increase in benefits under agreement U outperforms the savings in
abatement costs allowed by agreement DT. Therefore, individual countries are better off in agreement U [proposition 10(1)]. Remember that the level of fixed cost must be, at the same time, sufficiently low in this case, i.e., 2 ≥ \( \frac{2c_o}{w} \), given by the self-enforcing condition for the U agreement of proposition 9(1). As concerns global payoff, it is also higher in agreement U if the level of fixed cost is not too high [proposition 10(2)].

**Proposition 11:** If non-signatories do not abate \( (w < \sqrt{2c_o c}) \) and if the total number of countries is at least 3 \( (N \geq 3) \):

1. **The individual payoff under agreement DT** (with a coalition size of \( 2 + m \), with \( m \geq 1 \)) is higher than that under agreement U (with a coalition size of 2).
2. **The global payoff under agreement DT** is higher than that under agreement U if \( N \geq 4 \).
3. **The individual abatement under agreement DT** is higher than that under agreement U.
4. **The global abatement under agreement DT** is higher than that under agreement U.

**Proof:** See online Appendix.

When the fixed cost is sufficiently high \( (w < \sqrt{2c_o c}) \) and the total number of countries is at least 3, we know that the number of countries which abate is 2 for agreement U, and is equal to \( 2 + m \), with \( m \geq 1 \), for agreement DT. In this case, each country is better off under agreement DT than under agreement U [proposition 11(1)]. The receipt of transfer payments by the two countries in agreement DT provides each of them with the incentive to abate more [proposition 11(3)], and, in turn, to abate more at the global level [proposition 11(4)]. This leads to higher benefits from global abatement under agreement DT. Furthermore, the DT agreement is able to divide the abatement costs across the signatory countries by the means of transfer payments. Remember that the level of fixed cost must be, at the same time, sufficiently low in this case, i.e., \( m + 2 \geq \frac{2c_o}{w} \), given by the self-enforcing condition for the DT agreement of proposition 9(2). As concerns global payoff, it is also higher under agreement DT if the number of signatories is at least 4 [proposition 11(2)].

To sum up, it would appear that with linear benefit and quadratic cost functions, agreement U could sustain at most three signatory countries. This confirms the result of Barrett (1994). Hence, agreement U cannot substantially increase overall payoffs when the number of countries affected by the environmental problem is very high. However, agreement DT could lead to a coalition of at least three countries. In this case, when the fixed cost is high, the number of donor countries must be sufficiently high. By taking into account fixed costs in abatement technology, it would be possible to alter the pessimistic finding on the small number of signatories of an IEA that is reported in the literature. In this case, the agreement must be designed given the differentiated standards with transfers. That is, some of the countries should abate on behalf of all the other countries and pay
the fixed cost of abatement. The remaining coalition partners should then compensate them by transfer payments.

4. Conclusion
We investigate the relative efficiency of an agreement based on a uniform standard without transfers and one based on differentiated standards with transfers when strictly identical countries deal with transboundary pollution. We especially ask what role fixed cost plays. Two approaches are examined: the Nash bargaining solution, involving two countries, and the coalition formation framework, involving numerous countries and emphasizing self-enforcing agreements. In the former, in terms of welfare, strictly identical countries may wish to reduce their emissions in a non-uniform way under the differentiated agreement. For this result to hold, the fixed cost of investment in abatement technology must be sufficiently high. The nature of the threat point of negotiations, however, also plays a crucial role. As concerns global abatement, the two countries abate more under the uniform agreement than under the differentiated one. In terms of coalition formation when numerous countries are involved, a grand coalition could emerge under a differentiated agreement.

Our results highlight the fact that when the level of fixed cost – arising from the installation of an abatement technology – is accounted for, it could be optimal, even for perfectly symmetric countries, to sign an agreement based on differentiated abatement standards. This analysis could apply to similar and future environmental negotiations, in the case where the cost of the initial investment in abatement activities is too expensive for the countries. This cost could be split between the countries concerned by the environmental problem. This type of environmental cooperation is already on the European Union agenda in order to strengthen bilateral environmental projects involving southern and eastern Mediterranean countries within the framework of the European Union Neighborhood Policy.

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