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Cooperation among Asymmetric Countries: A Study for the Role of Side Payment in International Environmental Agreements

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Abstract By a survey of a range of existing literatures, this article makes a rough summary for previous theoretical findings about the role of side payment in international environmental agreements. If countries are symmetric, we can hardly exploit the transfer to enhance international cooperation. On the contrary, under asymmetric countries assumption, the side payment is often helpful to obtaining better global outcome in environmental issues. Even though no general theoretical conclusion can be claimed so far, many meaningful implications will be revealed with the going on of this article.

Key words Asymmetry, Coalition Stability, Side Payment/Transfer, Environmental Cooperation

Today, it is totally unnecessary to claim the importance of economic analysis for international environmental issues since the great amount of existing literatures can be regarded as the best evidence. Intrinsically the international environmental cooperation and conflicts among countries are game theory problems. In the past years, a few of good articles of literature review have given extensive collections for theoretical fruits obtained by economists. Howbeit most of these articles are too comprehensive to give readers clear results about specific problems. Here, as an attempt to avoid this limit, this paper would focus on the role of side payment in the international environmental agreement (IEA) formation, both in the frameworks of symmetric as well as asymmetric countries. This article is essentially still a literature review, but it would be definitely organized according to the classification of diverse situations in models instead of scholars' literatures. The author's goal is to provide an issue oriented systematic study of transfers' functioning in different settings, rather than an exhaustive presentation of past literatures. It is notable that side payment is relevant in various practical contexts beyond IEA. For example in public finance the inter-governmental transfer is frequently implemented, in public goods supply different districts usually contribute unequally which virtually facilitates intangible side payment. An immediate switch from this article's topic can be the role of side payment in domestic environmental cooperation among distinct regions. The wide applicability of side payment in public economics and environmental economics augments the value of this article's game theoretical methodology and conclusion.

In Section 1, the basic economic framework of global environmental cooperation would be offered. There, without introduction of transfers, the properties of cooperative stability would be slightly explored. After this section, the definitions of three kinds of usual transfer rules would be given in Section 2. Section 3 is the core of this article. There, first we demonstrate the uselessness of side payment when countries are identical. Secondly, choosing the paper of Carraro, Eyckmans and Finus (2006) as the skeleton, a series of detailed analyses and comparisons would show how side payment is helpful for asymmetric countries. At last in Section 4 a rough summary is presented. To be consistent, this paper will basically follow the good notations in Carraro, Eyckmans and Finus (2006) except some trivial revisions. Assume all the countries are presented by set $N=\{1, \cdots, n\}$, and there is at most 1 coalition, denoted as set $S=\{1, \cdots, s\}$, can be formed. Therefore, after mutual negotiation for coalition, the world can be expressed by the coalition structure $\{S, \{m\}, \cdots, \{n\}\}$ where countries $\{m, \cdots, n\}$ are $n-s$ non-signatories. Moreover, the empty set $\varnothing$ is used to declare the nonexistence of coalition.

1 The effect of asymmetry among countries on the stability of international environmental cooperation

A classically simple formulation of countries' welfare function with respect to emission abatement is powerful to demonstrate the global environmental game mechanism. Assuming there exist n countries, denote the welfare function for country i as

$$U_i=B_i-C_i=B_i(q_1, q_2, \cdots, q_i, \cdots, q_n)-C_i(q_1, q_2, \cdots, q_i, \cdots, q_n) \quad (1)$$

where function $B_i(\cdot)$ is the benefit from global emission reduction (which is mainly subjectively evaluated), $C_i(\cdot)$ is the emission abatement cost, and q_i country i's emission abatement. ①

In literatures, there are many diverse models which propose the benefit of international cooperation. Those prevailing

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models include the cooperative game models, non-cooperative models and partially cooperative models. When we discuss the possible equilibria in models, two benchmarks often serve as reference points of comparison: Full Cooperation (grand coalition) and Non-Cooperative Nash Equilibrium. The meaning of these two extreme cases is self-evident. In full cooperation circumstance, all countries are assumed to act to maximize the global aggregate welfare *i. e.* $\sum_{i \in N} U_i$. In contrast, non-cooperative Nash equilibrium refers to the consequence results from each party's fully selfish behavior. Latter, we will frequently resort to these two benchmarks. Also, the dynamics of models are critically relevant to conclusions. We can model an IEA negotiation as (often two stage) static game, (finitely or infinitely) repeated game or dynamic game.

1.1 Definition of stability of cooperation Without the existence of an effective international authority, the design of IEA should make it self-enforcing. To do that, we need to ensure two necessary and sufficient conditions: Profitability and Stability. Using the above defined notation, the profitability condition for signatories in an IEA can be expressed as

$$U_i(S) \geqslant U_i(\varnothing) \text{ for all } i \in S \quad (2)$$

which ensures that each signatory will be better off after participating in the IEA than in the non-cooperative Nash equilibrium. The definition of the stability of IEA is also clear and common in literatures. It is to say that, given an international agreement, neither signatories nor non-signatories have the incentives to deviate unilaterally from the IEA. It can be expressed in two equations:

$$\text{Internal Stability: } U_i(S) \geqslant U_i(S/\{i\}) \text{ for all } i \in S \quad (3)$$

$$\text{External Stability: } U_j(S) \geqslant U_j(S \cup \{j\}) \text{ for all } j \notin S \quad (4)$$

Equation (3) is called internal stability condition, it shows that the signatory countries will gain more staying in the coalition than withdrawal. Equation (4) is called external stability condition which indicates it is better to stay outside the coalition for non-signatory countries. And by definition, the coalition $S = N$ is always externally stable and coalition $S =$ (if it is regarded as coalition) is always internally stable. Often, game theorists use the term "coalition stability" instead of "stability of cooperation".

1.2 Gains of cooperation without side payment when countries are symmetric As mentioned above, cooperative game models, non-cooperative models and the mixture of both models are all alternatively used, since the selection of assumptions depends on the usage. Cooperative models can usually give more optimistic results while non-cooperative models are more pessimistic but realistic. The particular analysis conclusions differ with the natures of underlying models. Now we begin with the most basic setting: there are N countries, who face up trans-boundary pollution problem and hence manage to negotiate for a possible environmental cooperation. Without pointing out, no additional inter-governmental measures and instruments are imposed. Suppose now these countries are just debating on whose and how much emission abatement should be implemented without side payment. In general, the models with symmetric countries demonstrate that the possible stable coalitions are small, *i. e.* the amount of IEA signatories is small. Under this setup, almost all models furthermore show that the positive impact of coalition members' emission reduction on total emission abatement is also small. This consequence results from the severe incentive of free ride.

Recall the welfare function (1), without loss of generality, following Barrett (2005) as well as some other authors, it makes sense to further simplify it to the one with linear abatement benefit (constant marginal abatement benefit) and quadratic abatement cost (linear marginal abatement cost). Then, by constructing a frequently used two-stage game model (its structure is formally presented in section 3), we can find that a stable coalition in self-enforcing IEA can only consist of no more than 3 signatories, with no significantly larger gains than the non-cooperative Nash equilibrium outcome without IEA. Many other formulating of models verify the similar outcome (although in some models the scale of coalition is extended, the number of signatories is still far less than the total number of countries). Many classical literatures give good presence of this point in the context of diverse model specifications, such as Barrett (1997), Hoel and Schneider (1997). In Hoel and Schneider's paper, a specified example (they use emission as control variable and form a quadratic production gain function and linear damage function) is computed. Below in Table 1, I select some parts of their result related to this section and add the benchmarks of non-cooperative Nash equilibrium and grand coalition as comparison.

At first glance, the example seems to give exciting result that in Nash equilibrium the emission abatement coalition can include many countries. Indeed, when $N = 40$, a stable coalition has 24 members; when $N = 100$, it has 54. But, a fact which cannot be ignored is that there still exist about half countries who reject to join it. On the other hand, if we assess the success of the cooperation by the criterion of excess emission by using the intentionally defined term 'score', we can see the expanded scale of coalition is unfortunately accompanying with a decreased degree of emission abatement. Hence, here the undesirable result appears again: without additional instruments, the self-enforcing coalition cannot be said as quite successful.

1.3 Gains of cooperation without side payment when countries are asymmetric Will the framework of asymmetric countries make big difference to the above gloomy implications? The answer is NOT, unless some other mechanisms are introduced into the model (or say, reality). The asymmetry itself can not improve cooperation much.

It is obvious that the heterogeneity among countries should be reflected in the differences of welfare function. By setting that (using the general welfare function provided above), a great amount of researches had pointed out that, although the particular coalition in self-enforcing IEA depends on the specific form and parameterization of model, the main results remain disappointing. For asymmetric countries, the international environmental cooperation is yet quite limited, in the sense that the number of signatories is few and benefit from coalition is not significant. The behind intuition is that, since each country has a distinct benefit and cost function, without side payment an efficient allocation of abatement burdens within the coalition would generally result in an 'unfair' allocation of the cooperative gains among coalition members. The term 'unfair' is used in the sense that the gain each state received is disproportional to the abatement cost it borne. Hence without using transfer to compensate states who bear higher abatement cost, although a suggested large coalition can be collectively profitable, it can hardly be profitable for all participators. Frequently this violation of the profitability condition of some proposed members leads the difficulty of a large coalition's formation. And the higher is the heterogeneity among countries, the severer can this predicament be. Good references can be found in Barrett (1997) and Botteon and Carraro (1998).

Table 1 The result for symmetric countries without side payment, data selected from the example in Hoel and Schneider (1997)

Global emission level for diverse values of β, without side payment

N	n*	β = 0.1				β = 0.3			
		Non-Coop.	Nash Equil.	Full Coop.	Score	Non-Coop.	Nash Equil.	Full Coop.	Score
8	8	7.9	7.2	7.2	100.00	7.7	5.6	5.6	100.00
10	9	9.9	9.18	9	80.00	9.7	7.54	7	80.00
20	14	19.9	18.99	18	47.89	19.7	16.97	14	47.89
40	24	39.9	38.52	36	35.38	39.7	35.56	28	35.38
100	54	99.9	97.04	90	28.89	99.7	91.11	70	28.92

N	n*	β = 0.6				β = 0.9			
		Non-Coop.	Nash Equil.	Full Coop.	Score	Non-Coop.	Nash Equil.	Full Coop.	Score
8	8	7.4	3.2	3.2	100.00	7.1	0.8	0.8	100.00
10	9	9.4	5.08	4	80.00	9.1	2.62	1	80.00
20	14	19.4	13.94	8	47.89	19.1	10.91	2	47.89
40	24	39.4	31.12	16	35.38	39.1	26.84	4	34.93
100	54	99.4	82.23	40	28.91	99.1	73.34	10	28.91

Note: n* is the amount of signatory countries in equilibrium. And the term "score" use the two benchmarks' global emission level to evaluate the success of cooperation, the formula reads: Score = 100 * (Non-coop. emission − Nash equil. emission)/(Non-coop. emission − Full coop. emission). The higher is the score, the more fruitful is the coalition.

Howbeit, I am willing to point out again here, the above results for asymmetric countries is under the setting of asymmetry alone, without other additional mechanisms. If some artificial instruments can be added into, the result might not be so gloomy, at least in some situations. The possible instruments, which are often discussed, include side payment and issue linkage. This article focuses on the side payment.

Before closing this section, a brief discussion about the free ride problem which impairs the effectiveness and stability of coalition without side payment is necessary. During the optimization of deciding whether to join coalition and how much abatement to implement, each country would get a 'best reply function' with respect to others' emission reduction. This function reflects the interdependencies among countries' actions. Carraro and Siniscalco (1993) provide a pioneering study. The slope of best reply functions plays a critical role in the formation and stability of coalition, no matter under symmetric or asymmetric settings. When best reply function is negatively sloped, non-signatories will significantly increase pollution in response to the abatement of coalition members. This is called "leakage effect". Consequently, the cooperative parties would be damaged by free riders' behaviors. As a result the internal stability and even profitability cannot be satisfied for a coalition and hence ultimately the leakage effect undermines potential cooperation. However when the best reply function is orthogonal or nearly orthogonal, the leakage effect would not occur and non-coalition countries would not offset others' cooperation. In a nutshell, negatively sloped best reply function makes stable coalition difficult to exist and orthogonal one renders the stability more possible.

2 Different types of side payment

Side Payment is sometimes just called Transfer. Anyway, the meaning of side payment is self-evident. Side payment is the payoff (often refers to money, but of course many other forms are feasible) transferred from some countries to other countries as reward in order to give the latter incentives to join the IEA. The direct aim of side payment is to compensate the emission abatement costs of the latter countries, to make them at least not worse off by entering the coalition. Naturally, a crucial issue is to know how the amount of side payment is determined and who are the receivers or donors. This matter is proceeded according to the so-called "burden sharing rule" or simply "side payment rule".

Before the study of specific rules, we first need to distinguish 2 groups of transfers.[②] (1) Ex-Ante Transfer, which means that before the formation of IEA, countries commit to a certain transfer rule designed for all signatories. The ex-ante transfers only matter the coalition members but not non-signatories. Typically, 3 kinds of ex-ante burden sharing rules, Nash Bargaining rule, Shapley Value rule and Chander-Tulkens rule have been frequently investigated in existing literatures (In section 3, a newly designed rule will be cited. But let me postpone the presentation of its definition there). (2) Ex-Post Transfer, which means that after the formation of coalition, transfers are used to expand the coalition. Among the ex-post transfers, following Carraro and Siniscalco (1993), there are 2 types: (a) Type 1 Expansion, signatories bribe non-signatories to join the coalition and (b) Type 2 Expansion, non-signatories bribe other non-signatories to join. Note that ex-post transfers are typically not only paid to the new coalition member(s), but also to a set of old signatories to keep the stability of expanded coalition.

It is not trivial to note that the particular results of international cooperation models depend heavily on the used rule. Howbeit, while the ex-ante transfer rules have become regular instruments used in articles studying the environmental side payment, the ex-post transfers are yet relatively less probed. This phenomenon might somewhat result from the clear and widely accepted mathematical structure of three ex-ante rules, which property is preferred by modern economic analysis. Below the three ex-ante rules' definition are given. More discussion can be found in section 3.

2.1 Nash bargaining rule The Nash bargaining rule is derived from the famous Nash bargaining solution. In Nash bargaining rule, emissions are determined by maximizing the product of the deviation of cooperative countries' welfare from their non-cooperative Nash equilibrium level. In definition, for coalition of n countries $\{1, \cdots, i, \cdots, n\}$, it is the solution to

$$\underset{\{x_i\}}{\mathrm{Max}}(U_1 - U_1^o)^{\beta_1}\cdots(U_i - U_i^o)^{\beta_i}\cdots(U_n - U_n^o)^{\beta_n} \quad (5)$$

or for simplicity of calculation, equivalently

$$\underset{\{x_i\}}{\mathrm{Max}}\ \beta_1\ln(U_1 - U_1^o) + \cdots + \beta_i\ln(U_i - U_i^o) + \cdots + \beta_n\ln(U_n - U_n^o) \quad (5')$$

where U_i is the welfare from cooperative emission and U_i^o the utility from non-cooperative level. The parameter β_i is a weight for country i's benefit, which measures the individual bargaining power. In most literatures, an equal bargaining power *i.e.* $\beta_i = 1$ for all i is assumed.

However, so far the above formula only tells every signatory's optimal emission level. But the welfare a country obtains is the one result from emission plus a net side payment. Obviously, when countries are identical, the equation (5) is enough since no intra-coalition side payment is needed. But when asymmetric setup appears, without transfers some countries would be at suboptimal position from individual viewpoint since equation (5) is oriented by coalitional optimum. Then the intra-coalition transfers are indispensable. Ultimately depending on the bargaining power, the Nash bargaining rule makes every country to obtain an after-transfer welfare equal to its non-cooperative Nash equilibrium utility plus a weighted share of aggregate coalitional cooperation surplus relative to non-cooperation, *i.e.*

Nash Bargaining Rule

$$T_i^{NB}(S) = -[U_i(s) - U_i(\varnothing)] + \frac{\beta_i}{\sum_{j\in S}\beta_j}[\sum_{j\in S}U_j(S) - \sum_{j\in S}U_j(\varnothing)] \quad (6)$$

$$\hat{U}_i^{NB}(S) = U_i(\varnothing) + \frac{\beta_i}{\sum_{j\in S}\beta_j}[\sum_{j\in S}U_j(S) - \sum_{j\in S}U_j(\varnothing)] \quad \forall i\in S \quad (7)$$

here T is the amount of transfer. Clearly the non-cooperative Nash equilibrium is the benchmark. If equal weight is set, (7) becomes

$$\hat{U}_i^{NB}(S) = U_i(\varnothing) + \frac{1}{s}[\sum_{j\in S}U_j(S) - \sum_{j\in S}U_j(\varnothing)] \quad \forall i\in S \quad (7')$$

2.2 Shapley value rule Stemmed from Shapley (1953), Shapley value is an important solution concept in cooperative game theory. Invoking Barrett (2005), "the Shapley value distributes the gains to cooperation by means of side payment that average each player's marginal contribution to the different coalitions that might form". The calculation of Shapley value is complicated when the number of countries N is large. Barrett (1997) provides a detailed expression for Shapley value when $N = 3$. In formula, this rule is exploited according to:

Shapley Value Rule

$$T_i^{sv}(S) = -U_i(S) + \sum_{T\subseteq S,\, i\notin T}\frac{t!\ (s-t-1)!}{s!}[\sum_{K\in T\cup\{i\}}U_k(T\cup\{i\}) - \sum_{k\in T}U_k(T)] \quad (8)$$

$$\hat{U}_i^{sv}(S) = \sum_{T\subseteq S,\, i\notin T}\frac{t!\ (s-t-1)!}{s!}[\sum_{K\in T\cup\{i\}}U_k(T\cup\{i\}) - \sum_{k\in T}U_k(T)] \quad \forall i\in S \quad (9)$$

where $T\subseteq S$, t and s are the dimension of T and S.

As shown, Shapley value rule takes all possible sub-coalition formation into account. In Carraro, Eyckmans and Finus (2006)'s words, it gives "every country a valuation according to its marginal contribution to every possible sub-coalition T of S (term between square brackets), weighted by the probability that this sub-partition forms".

2.3 Chander-Tulkens rule Another important burden sharing rule, with several advantages, is proposed by Chander and Tulkens (1994).

Chander-Tulkens Rule

$$T_i^{CT}(S) = [U_i(S) - U_i(\varnothing)] + \frac{D'_i(\varnothing)}{\sum_{j\in S}D'_j(\varnothing)}[\sum_{j\in S}U_j(S) - \sum_{j\in S}U_j(\varnothing)] \quad (10)$$

$$\hat{U}_i^{CT}(S) = U_i(\varnothing) + \frac{D'_i(\varnothing)}{\sum_{j\in S}D'_j(\varnothing)}[\sum_{j\in S}U_j(S) - \sum_{j\in S}U_j(\varnothing)] \quad \forall i\in S \quad (11)$$

with D'_i the marginal damage of emission.[3] It is not difficult to realize that Chander – Tulkens rule can be just regarded as a Nash bargaining rule with unequal weights. However, as a particular case of Nash bargaining rule, it faces with more dilemma than its more general counterparts as well as Shapley value rule. This rule is firstly suggested in a cooperative game framework, which is optimistic but not realistic (but of course this is also the case for another two rules). And this rule is based on assumptions about parties' beliefs and credibility that one's withdrawal from an IEA will result in a complete collapse of cooperation, which add the difficulties to make this rule practical. Furthermore, this rule is more information demanding: to employ it a knowledge of function $D_i(\cdot)$ is required while the weights in a simple Nash bargaining rule can be decided directly in negotiation. Hence, most recent researches focus on the former two rules rather than this one. Some brief comments about this rule, also the relation of three rules to the "core" concept, can be found in Barrett (2005).

3 The role of side payment in international environmental agreements

It is both arbitrary to say side payment is helpful or not helpful in IEA, since the results directly depend on the model structures (*e. g.* cooperative/non-cooperative, static/dynamic, and any mixture of properties) and applied side payment rules. More extensive assumptions are also relevant, such as the degree of asymmetry among countries and the existence of commitment. Intuitively, compared to no side payment case, the introduction of side payment into the model introduces the possibility that the original non-signatories reduce their emission in exchange for transfers. Accordingly a Pareto improvement is possible. Unfortunately a review of a range of literatures will show it is really difficult to get general conclusion about under which kind of circumstance the side payment can function well. A more feasible way I used here is to sort some evident types and provide detailed analytical examples.

3.1 If countries are symmetric Side payment is usually considered in the context of asymmetric countries. In intuition, when some countries have more benefit from emission abatement or suffer more damage from the emission than some other countries, they will have strong incentives to pay some interests to ask other countries to join the emission abatement coalition. On the other hand, countries with lower abatement cost are apter to be bribed to join IEA. In contrast, when countries are symmetric, the incentive of paying or receiving side payment will be significantly diminished and the achievement of coalition with side payment will also be accordingly small.

The convincing analysis of Carraro and Siniscalco (1993) demonstrated the difficulty to expand the cooperative coalition among symmetric countries even with side payment. They assume a usual welfare function $U_i = B_i - D_i = B_i(x_i) - D_i(x_1, x_2, \cdots, x_i, \cdots, x_n)$ (analogous to our equation (1') except that their $B_i(\cdot)$ only depends on x_i) and a two-stage game. By using the internal stability condition, they prove that if no further helpful instrument is introduced, side payment cannot broaden coalition among symmetric countries. Or from the viewpoint of stability, say, the proposed expanded coalition is Not Stable even though side payment is employed. To make transfer useful, a minimum degree of countries' commitment to their strategies need to be imposed. And the effect of side payment on cooperation (to be more precise, two focal points: the possibility of expanding current coalition to larger stable coalition, the size of largest possible stable coalition by applying all feasible side payment forms) critically relies on the exact form of commitments. Unfortunately, it is hard to give binding (ensure enforcement by outside power) or credible (ensure enforcement by self-incentive) commitments from countries within modern international laws context. Thereby, side payment for symmetric parties is not such a compelling research issue.

Amazingly sometimes the use of transfer for symmetric countries can even damage cooperation. This is the topic in Hoel and Schneider (1997), whose argument also concerns about commitment. As mentioned above, the introduction of side payment into the model has a positive effect that it introduces the possibility of the original non-signatories' emission abatement in exchange for transfers. On the other hand, a negative impact is simultaneously injected: "the prospect of receiving a transfer for reducing one's emission provided the country does not commit itself to cooperation, tends to reduce the incentive a country might have to commit itself to cooperation". If this negative effect of transfer, called "disincentive effect", is strong enough, the application of transfer can conversely make cooperation worse. Below I list some selected results with side payment from their paper's example in Table 2. Reader can easily find how international coalition degenerates (both in the shrinkage of stable coalition size and increment of aggregate emission), compared to previous Table 1.

Table 2 The result for symmetric countries with side payment, data selected from the example in Hoel and Schneider (1997)

Global emission level for diverse values of β, with side payment									
N	n*	β = 0.1				β = 0.3			
		Non-Coop.	Nash Equil.	Full Coop.	Score	Non-Coop.	Nash Equil.	Full Coop.	Score
8	8	7.9	7.2	7.2	100.00	7.7	5.6	5.6	100.00
10	6	9.9	9.36	9	60.00	9.7	8.08	7	60.00
20	3	19.9	19.62	18	14.74	19.7	18.85	14	14.91
40	3	39.9	39.61	36	7.44	39.7	38.82	28	7.52
100	3	99.9	99.6	90	3.03	99.7	96.81	70	9.73
N	n*	β = 0.6				β = 0.9			
		Non-Coop.	Nash Equil.	Full Coop.	Score	Non-Coop.	Nash Equil.	Full Coop.	Score
8	8	7.4	3.2	3.2	100.00	7.1	0.8	0.8	100.00
10	6	9.4	6.16	4	60.00	9.1	4.24	1	60.00
20	3	19.4	17.69	8	15.00	19.1	16.54	2	14.97
40	3	39.4	37.65	16	7.48	39.1	36.47	4	7.49
100	3	99.4	97.62	40	3.00	99.1	96.43	10	3.00

Nevertheless the implications offered by this paper that transfer can sometimes harm cooperation should not be simply read as transfer is "bad". In fact, there is no reason to forbid signatory countries' "discarding right", *i. e.* if original coalition members realize the damage of transfer, they can simply choose to not introduce it into negotiation process. An additional option of transfer for signatories relative to initial non-transfer world should make them at least not worse off. Even without this "discarding right" argument, a slight adjustment of Hoel and Schneider's model assumption can be sufficient to avoid the excessively strong "disincentive effect". Barrett (2001) gives a comment about that for asymmetric countries, see footnote 7 of his paper.

3.2 If countries are asymmetric The mathematical hardness of analyzing asymmetric countries explosively rises with the increase of amount and types of countries. This is particularly obvious after introducing into the side payment. That is why many of the literatures for transfer among asymmetric parties only provide numerical solution for a given example rather than mathematically analytical expression. Definitely the asymmetric assumption is most close to our real world. With a balance of reality and operability, common researches which try to give numerical simulation for the world would divide it into several main parts. For instance, as a classical attempt Botteon and Carraro (1997) makes the partition of 5 major countries/districts: (1) Japan (2) US and Canada (3) EU (4) Eastern Europe and Russia (5) India and China.

A rough summary for published papers can state that: under strong asymmetry adding some necessary conditions, skillful use of side payment can indeed enhance the cooperation – coalition can be expanded and the cooperative benefit be enlarged. Below, taking Carraro, Eyckmans and Finus (2006) as skeleton and some other articles complement, a set of issues for asymmetric countries are investigated.

In this recent paper, Carraro, Eyckmans and Finus use an empirical model, in which the world is divided into 6 districts, demonstrates the effects of Nash bargaining rule, Shapley value rule and Chander-Tulkens rule in IEA coalition. Moreover, they manage to obtain an "Optimal Transfer Scheme" and show that the "optimal" rule can bring better outcome than the previous three classical rules. After that they go further to study a series of issues for ex-post transfers.

Their empirical data of simulating the world comes from the CLIMNEG World Simulation Model (CWSM) (see Eyckmans and Tulkens (2003) for more details). In CWSM each country/district i maximizes its welfare by the decision of the long run time path of two control variables *i. e.* carbon emission abatement $q_{i,t}$ and investment $I_{i,t}$. The welfare of country i is $U_i(\omega)$ where $\omega = \{I_{i,t},\ q_{i,t}\}_{i\in N;\ t=0,\cdots,\Omega}$ is the economic strategy vector consists of all $q_{i,t}$ and $I_{i,t}$ decisions within time horizon Ω of all countries because of externality.

In CWSM the world is partitioned into 6 districts: USA, JPN (Japan), EU (European Union), CHN (China), FSU (Former Soviet Union) and ROW (Rest of the World). Compared to Botteon and Carraro (1997) a new player ROW is considered, latter we will see this modification makes sense. Different parameter values should be allocated to countries in calibrating the CWSM to reflect the heterogeneity. (a) USA, JPN and EU face steep abatement cost curves $C_i(\cdot)$, FSU with moderate and CHN and ROW with flat ones. (b) EU and ROW have steep damage curves $D_i(\cdot)$, USA and JPN with moderate and CHN and FSU with flat ones. The reason for assigning certain slopes for each parties' $C_i(\cdot)$ and $D_i(\cdot)$ functions is interpreted in the paper. Since we have 6 players, we will have 58 different possible coalitions (including the case of coalition $S=\varnothing$). For every possible coalition S, compute the Nash equilibrium $\omega^*(S)$ to derive welfare (in their paper the term "valuation" and accordingly $V_i(\cdot)$ instead of $U_i(\cdot)$ is used) $U_i(S) = U_i(\omega^*(S))$ for each player *i*. And world welfare is $\sum_{i\in S} U_i(S)$.

As usual, the IEA formation is modeled as a Two-Stage Game, consistent with tradition in many literatures. In Stage 1 countries decide whether to join coalition (assume at most 1 coalition will be formed), and in Stage 2 countries choose their economic strategies (two strategic variables: emission abatement and capital investment). The notation for world $N=\{1,\cdots,n\}$ and coalition structure $\{S,\{m\},\cdots,\{n\}\}$ is used as previously hung. The solution of this game must be a Subgame Perfect Equilibrium. At stage 2 there is the Nash Equilibrium for Strategies, in which each non-signatory acts non-cooperatively to maximize its individual utility and all signatories act cooperatively to maximize the aggregate coalition welfare $\sum_{i\in S} U_i(S)$. At stage 1 there is the Nash Equilibrium for Participation, where is expressed by the Profitability and Stability conditions (internal and external stability). ④

By solving the subgame perfect equilibrium of this two-stage game using the data of CWSM, further analysis with implications for reality can be done. From pure theoretical insight, there are two basic inferences for asymmetric countries which are robust. (1) Unambiguously a big difference in equilibrium solutions between symmetric and asymmetric countries setup is that: for symmetric world, the achievement of IEA is completely independent of the identity of coalition member; but under asymmetric setting, not only the size of coalition but also the specific identity of membership are crucial indexes for coalitional success. Under strong asymmetry the latter index could be dominant. (2) The countries with lower (marginal) emission abatement cost and/or higher (marginal) pollution damage are more efficient in international environmental cooperation in terms of global welfare. In other words, it is in principle better to motivate these kinds of countries to join the coalition, all else being equal. In the paper authors compute all 58 possible Nash equilibria and rank them by global welfare level (see Table 1 in their paper). As expected the above two theoretical inferences are confirmed. Through the ranking they find that ROW and CHN are the two most important players in IEA formation in terms of global welfare, since this two have the cheapest abatement cost. Based on this finding they anticipate that an effective climate agreement should include developing countries ROW and CHN. The above two points (1) and (2) are conveyed by Botteon and Carraro (1997) in a more compact way: "the conclusion that the country with the highest marginal damage is the pivot around which environmental coalitions can be formed is quite robust". Depending on its parametric assumptions, this (1997) paper finds all stable coalitions must include the player India + China, since this one is set to have the highest marginal damage.

As discussed in section 1.3, if no transfer mechanism is exploited, for asymmetric countries the stable coalition is expected to be small with not large cooperative achievement. This is verified in this paper. Even more striking, simulation from CWSM data exhibits that there is not any stable coalition. While there would be few small stable IEAs in many other papers' simulations (for example, in Barrett (1997) without transfers there are 2 coalitions of size 2), such an extreme case here demonstrates how difficult even a small partial cooperation could be if no side payment.

3.2.1 The role of ex-ante transfer. Recall the definition of Nash bargaining rule, Shapley value rule and Chander-Tulkens rule given in section 2. Carraro, Eyckmans and Finus call them "simple transfer schemes". Under superadditivity (introduced latter), it can be prove that all the three simple transfer rules have an advantage of guaranteeing profitability for all signatories in any coalition. More importantly, consistent with many earlier papers, this paper finds that the simple transfers indeed promote the cooperation among asymmetric states compared to non-transfer outcome. Resorted to the application of simple transfers, the size of stable coalition is enlarged and higher global welfare is obtained. Similar results can be found in Botteon and Carraro (1997, 1998) for instance. However even though this result is true in a number of situations, it is Not General. Two uncertainties should be addressed if we construct a new model. (1) Uncertainty about whether transfer can necessarily help. Analogous to that for symmetric one mentioned above, it is not impossible that simple transfer can sometimes harm cooperation within asymmetric structure. In Barrett (2001), if we use Chander-Tulkens cost sharing rule, the total net benefits for all countries would reduce after the introduction of side payment. In Hoel and Schneider (1997) the use of transfer results in the size reduction of largest stable coalition with indeterminate overall effect on emissions. Resulting in a moderate disappointment, Barrett (1997) investigates the impact of Nash bargaining and Shapley value rule in a hypothetical heterogeneous example, and find that the help of transfers is nearly negligible for his example. (2) Uncertainty about which transfer rule can do better. In Carraro, Eyckmans and Finus (2006), the Nash bargaining rule leads to a stable coalition with highest global welfare. However no generalization could be made about which rule is better. Each model can yield its own result. In Botteon and Carraro (1997) one of the core conclusions is that the different burden sharing rules have distinct effectiveness and can make significantly different help. Within this paper (1997), with Nash bargaining rule of transfer, commitment is indispensable. Otherwise the expected larger coalition cannot be achieved. But by using Shapley value rule instead, countries can avoid this dilemma since then commitment is unnecessary. Combining these two uncertainties, theoretically any possible rankings for all three simple rules and non-transfer outcomes can probably happen, depends on specific models and parameterizations.

A main contribution of Carraro, Eyckmans and Finus (2006) paper is that they propose a new ex-ante transfer rule, so-called "optimal transfer scheme", as a transcendence upon the three classical rules. But put in advance, in the paper authors impose two properties for the welfare/valuation function. The reasonings, proofs, discussions and conclusions for transfer in this paper, are significantly based on these two properties. This two important properties hold for the values of welfare functions derived from CWSM model, hence in this paper they are "fact". But from the pure theoretical viewpoint they are no more than "assumptions", regardless of that they are "very general" as proposed by authors. This distinguishing is crucial to understanding this paper's framework. Below I cite the definitions from their paper:

A coalition game exhibits Superadditivity if and only if

$$\sum_{i\in S\cup\{j\}} U_i(S\cup\{j\}) > \sum_{i\in S} U_i(S) + U_j(S) \text{ for all } S\subset N \text{ and } j\notin S \quad (12)$$

A coalition game exhibits Positive Externality if and only if

$$U_l(S\cup\{j\}) > U_l(S) \text{ for all } S\subset N,\ j\notin S \text{ and all } l\notin S\cup\{j\} \quad (13)$$

Clearly superadditivity makes cooperation attractive and positive externality makes free riding attractive. Therefore a country's decision to join a coalition and hence the coalition stability depends on the intensity of superadditivity effect relative to that of positive externality effect.

Then a concept of "Potentially Internally Stable Coalition (PISC)" is introduced. A coalition S is a Potentially Internally Stable Coalition (PISC) if and only if

$$\sum_{i\in S} U_i(S) \geqslant \sum_{i\in S} U_i(S\setminus\{i\}) \quad (14)$$

Obviously PIS is a necessary condition for Internal Stability. If a coalition is PIS, then it would have sufficient resources to ensure each signatory to get at least as much payoff as that if it unilaterally quits the IEA. Hence naturally we can use the unilateral deviation utility $U_i(S\setminus\{i\})$ as threat point to guarantee internal stability for all signatories.

A transfer rule is an Optimal Transfer Scheme (OPTS) if

$$T_i^{OP}(S) = -[U_i(S) - U_i(S\setminus\{i\}] + \lambda_i[\sum_{j\in S} U_j(S) - \sum_{j\in S} U_i(S\setminus\{i\}] \quad (15)$$

$$\hat{U}_i^{OP}(S) = U_i(S\setminus\{i\}) + \lambda_i[\sum_{j\in S} U_j(S) - \sum_{j\in S} U_i(S\setminus\{i\}] \text{ for all } i\in S \quad (16)$$

with $\sum_{i\in S}\lambda_i = 1$. Obviously the idea of OPTS, with weight λ_i, is analogous to that of Nash bargaining and Chander-Tulkens rule. The authors points out that OPTS has several advantages. For example any OPTS rule will make any PISC internally stable, each coalition that is internally stable under a simple transfer rule will also be internally stable under OPTS. Due to superadditivity and positive externality, the coalition with the highest global welfare among all PISCs is also externally stable and hence stable. Therefore "any OPTS exploits the full potential of self-enforcing cooperation" and will necessarily yield at least not lower (higher or equal) global welfare than all three simple rules as well as non-transfer outcome. In other words this suggested "optimal transfer scheme" resolves both two above "uncertainties": (1) OPTS can necessarily help improve global welfare, at least it will result in a same utility level as no side payment (2) OPTS can certainly do better than any simple rule. Howbeit, while celebrating the success of this paper that it designs a very helpful ex-ante transfer rule with bright prospect for application, it is equally crucial to remind that the merits of OPTS ground on the assumptions of Superadditivity and Positive Externality. If a model without superadditivity and positive externality properties is to be analyzed, the use of OPTS needs more reconsideration.

3.2.2 The role of ex-post transfer. After a coalition is formed with or without ex-ante transfer, the next thing is to consider the potential of ex-post transfer to expand it. First we can check the possibility of Type 1 Expansion – signatories bribe non-signatories to join the coalition. The sufficient and necessary conditions for type 1 expansion to be possible are (a) the expansion gives a Pareto improvement to all old members of S and new member(s), and (b) the expanded coalition is internally stable. With superadditivity and positive externality holds, it can be proved that if OPTS was already employed previously, then type 1 expansion is no longer needed (and unfeasible if one tries to do it). That is, the potential of type 1 expansion to increase global welfare has already embodied in OPTS. In contrast the use of a simple ex-ante rule would make the analysis for type 1 expansion chaotic. So far no robust law can be followed to directly pick out the best type 1 expansion candidate from several stable coalitions (if existed) formed with simple ex-ante transfer rule. A time consuming one-by-one check might apply.

After the potential of type 1 expansion is exhausted, we then check the Type 2 Expansion – non-signatories bribe other non-signatories to join. The sufficient and necessary conditions for type 2 expansion to be possible are the same as (a) and (b) for type 1 expansion, and (c) the expansion gi ves a Pareto improvement for the outsider(s) who supply the transfer. Under superadditivity and positive externality assumptions, after OPTS is used, the conditions (a) and (b) can be relaxed to the single one that the new larger coalition is PIS, keeping condition (c) unchanged. In intuition, there are two plausible conjectures for the roles of countries in type 2 expansion for heterogeneous structure. (1) The non-signatory states with high abatement cost and/or high environmental damage cost will have more motivations to unilaterally bribe other non-signatories to join IEA. This kind of countries are more likely to act as donator for type 2 expansion. (2) Non-signatory countries can still make a significant help in the success of IEA, even if they are not coalition members. By paying side payment to other non-signatories, those countries can efficiently, in their own interests, motivate others to participate in IEA. As a result the IEA size could be enlarged and global welfare improved. These two intuitions are both confirmed by the simulation in Carraro, Eyckmans and Finus (2006). This paper's simulation shows that only USA (with steep abatement cost and moderate damage cost in CWSM setup) and EU (with steep abatement cost and steep damage cost) can sponsor the type 2 expansion, both result in a large global welfare gain. Above theoretical analysis for type 2 expansion has good implication for post-Kyoto international climate negotiations. In the past years, international society was annoyed much about some important industrialized countries' non-cooperation in IEAs, such as USA and Canada. The finding here suggests a new road for the design of future IEAs, which allows someones to still stay outside the coalition but contribute financially to expand and stabilize a coalition. For example USA can be involved in prospective protocols in which it is responsible to financially aid developing countries to reduce emission and become a complete member of coalitions. Of course some analogous mechanisms already functioned in certain fields in reality, while some theoretical supports from point of view of side payment are formally proposed here.

To close section 3 here, I decide to harp on the same string. In economic analysis conclusions always tie tightly to the specific presumptions. The effectiveness of transfer for asymmetric countries cannot be claimed in isolation. In Barrett (2001)'s model, side payments on their own have virtually no effect on the outcomes of self-enforcing IEA, unless the inter-countries heterogeneity is strong enough to alter the rules of the game. Clearly in his model the impacts of transfer rely on the degree of asymmetry. This empirically positive correlation between asymmetry and transfers' usefulness appears in a great amount of literatures, but a rigorous theoretical induction is lacking. Some other factors such as commitment also partially determine whether transfers can really help. The revelation of side payments' disability in a few of models is not surprising.

4 Conclusions

This paper managed to give an issue oriented review of the main developments in literatures for the role of side payment in IEA. Because of the limit of author's ability, it is no more than a highly preliminary study. A set of important topics are not addressed. For example it is also meaningful to discuss the tangible way side payment can be executed in reality, rather than the abstract "rules". An inspection on the various instruments such as introducing supranational institutions to manage the side payment, deposit tool, monetary (currency) transfer, in-kind transfer, is certainly valuable (Schmidt (1998) gives a short investigation). But I hope leastwise the topics dealt within the current paper provide a not confusing sorting from tremendous amount of literatures. Roughly speaking, the diverse cases analyzed in section 1 and 3 can be summarized in the following matrix:

	without Side Payment	with Side Payment
Symmetric Countries	Unstable, Limited cooperation	Unstable, Limited cooperation
Asymmetric Countries	Unstable, Limited cooperation	Stable, Improved cooperation

Provided a lot of counterexamples before, explicitly this matrix is not an absolute theoretical conclusion but merely an empirical induction from many models. So far there exist no general theoretical conclusions yet, all assertions about the role of side payment cannot be divorced from the definite expression of assumptions and burden sharing rules.

In the future a grand careful sensitivity analysis should be done in order to verify under which conditions, assumptions, models, function forms, parameterizations, regional partitions *etc.*, some results hold or not. For instance we can relax the superaditivity and positive externality assumption used in Carraro, Eyckmans and Finus (2006) to see if OPTS is still helpful. Or we allow the possibility of multiple coalitions formation, add endogenous or exogenous shocks in the game, try a repeated or dynamic game model, consider the asymmetric information and so forth. Moreover we can inject the political negotiation part into the model since the IEA formation is intrinsically a political-economic procedure but rare literatures have done that. Harstad (2008) is a recent attempt in which it explores the transfer in the context with strategic delegation of negotiation, and finds that " side payments are bad if the heterogeneity is small while the uncertainty and the typical value of the project are large". Nevertheless saying is always easier than doing, in the field of side payment economists have a long way to go.

Note: ① (i) In many articles, emission abatement cost $C_i(\cdot)$ only depends on the abatement effort of the individual country i who manages to reduce emission. However, due to the externalities, sometimes abatement cost will also depend on other countries' abatement (for example, Germany's air pollution damages the health of French workers and hence reduces the productivity in France, the lowered productivity makes the emission reduction cost in France higher).

(ii) Alternatively, we can form the welfare function with respect to the quantity of emission:

$$U_i = B_i - D_i = B_i(x_1, x_2, \cdots, x_i, \cdots, x_n) - D_i(x_1, x_2, \cdots, x_i, \cdots, x_n) \quad (1')$$

where $B_i(\cdot)$ is the gain by emitting pollutant, $D_i(\cdot)$ is the damage from pollution (mainly subjectively evaluated), and x_i country i's emission. It is not difficult to see the equivalence of these two formations. See Ioannidis, Papandreou and Sartzetakis (2000).

(iii) It is also feasible to use the way of minimizing the total cost function instead of maximizing the welfare function. Total Cost is the sum of emission abatement cost and damage cost:

$$TC_i = C_i + D_i = C_i(q_1, q_2, \cdots, q_i, \cdots, q_n) + D_i(q_1, q_2, \cdots, q_i, \cdots, q_n) \quad (1'')$$

or

$$TC_i = C_i + D_i = C_i(x_1, x_2, \cdots, x_i, \cdots, x_n) + D_i(x_1, x_2, \cdots, x_i, \cdots, x_n) \quad (1''')$$

Chander and Tulkens (1994) use this manner. Definitely a linear transformation to $C_i(\cdot) + D_i(\cdot)$ would give $B_i(\cdot) - C_i(\cdot)$ or $B_i(\cdot) - D_i(\cdot)$ respectively in our equation (1) and (1′).

② Carraro and Siniscalco (1993) give an initially systematic investigation for types of transfers. Carraro, Eyckmans and Finus (2006) classify them into such approachable groups that I generally follow them.

③ In some papers, the argument in the weight is B'_i rather than D'_i where B'_i is the marginal benefit of pollution abatement. This alternative formation in fact makes no difference, by the same reason as in footnote ① (ii).

④ Unexpectedly in Carraro, Eyckmans and Finus (2006) the profitability condition is ignored. I cannot find an interpretation to not add it here.

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