

# Climate coalitions and international trade: assessment of cooperation incentives by issue linkage

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## Abstract

This paper investigates climate control coalition games. It studies whether incentives exist for non-cooperating nations like the USA to join a coalition based upon issue linkage. Issue linkage is considered through increased R&D expenditures triggering improved technological innovations that advance energy efficiencies. Model calculations demonstrate that incentives exist for non-cooperating countries like the USA to join a climate control coalition if nations cooperate on technological innovations. Restrictions on trade such as sanction mechanisms against non-cooperating countries are not necessarily an incentive to join a coalition. Technological spillover effects lead to improved economic situations and increased energy efficiencies in non-cooperating countries. © 2003 Elsevier Ltd. All rights reserved.

*Keywords:* Climate change policies; Coalition games; Induced technological change

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## 1. Introduction

Scientific investigations will most likely reveal that continued accumulation of anthropogenic greenhouse gases (GHGs) will ultimately have severe consequences on the climate as well as ecological and social systems. Irreversible climate changes induce significant costs, and no future efforts can reverse the resulting damage. International climate control agreements intend to relieve this process. A substantial reduction of GHG emissions requires cooperation between countries. However, greenhouse gas emissions reduction is still an international public good necessitating long-term and global economic efforts. The formulation of the Kyoto protocol and its ensuing negotiation attempts represent one initial outcome of cooperative international climate control policy actions.

Latest negotiation outcomes confirm that individual countries are mainly concerned with potential economic disadvantages resulting from emissions reduction. Maximization of national welfare leads to either unilateral operations, a formation of small coalitions or “free rider” actions. Whether a stable coalition can be reached depends on the opportunities to reduce interest conflicts regarding a minimum agreement. A bargaining situation

contains opportunities to collaborate for mutual benefits. As real negotiation processes demonstrate, a full agreement of all players is unlikely. More realistically, some players may act independently or unilaterally to maximize their own welfare and self-interests, while other players create small and stable coalitions (Carraro and Siniscalco, 1992; Carraro and Siniscalco (1993); Hoel, 1994). The decision to join a coalition or initiate a partial coalition depends on the difference in net benefits of a cooperative and a non-cooperative strategy (Barrett, 1994). As long as the environment and climate are treated as a public good and there are no penalties or sanction mechanisms for polluting entities, there will be no economic incentives for unilateral or cooperative action to protect the environment. Moreover, as long as cooperative behavior is imposed by voluntarily actions, finding a common or global agreement will be driven by the varying interests of negotiating countries. These interests must be harmonized between nations or groups of countries.

A variety of free rider incentives exist. A free riding position is seen in the recent decision of the US to leave the previously established climate control coalition. This paper explores the scope of cooperation for greenhouse gas emissions reduction by using game theoretic approaches. The purpose of this paper is to investigate whether incentives exist for free riding countries to join an existing international climate control cooperation

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coalition. The payoffs for all players are contrasted and assessed by a world integrated assessment model. Different incentives to cooperate are analyzed by diverse assumptions regarding future impact assessment. Issue linkages are studied by combining climate control targets with increased R&D expenditures that trigger environmentally friendly technologies. Furthermore, Barrett's idea of issue linkage of joint climate control cooperation and trade patterns is compared. Section one of this paper gives a brief overview of international climate control agreements. Section two describes the game theoretic approach of issue linkage. Sections three briefly illustrates the modeling framework used to study these impacts, while section four shows the main modeling results. The last section concludes.

## 2. International climate control coalitions

The greatest success of international climate control policy was the establishment of the Kyoto protocol. It is one of the leading and most important international environmental agreements in the history of global negotiation and bargaining policies. However, recent climate change negotiation processes confirm that the initial climate change control coalition was not stable: The United States, the world's largest economy and emitter of GHGs left the coalition and now acts as a singleton and free rider. The reason for this behavior can be explained by game theoretic validation: Economic payoffs for free riding are higher than joining the coalition.<sup>1</sup> This paper confirms this by global modeling results. Because the remaining climate coalition partners still intend to reach an international climate control agreement, the environmental effectiveness is potentially diminished. International greenhouse gas reductions imposed by the Kyoto protocol can most likely not be met.

A variety of incentives exist for free riders or instable coalition partners to join or remain in the game. Carraro and Siniscalco (2002) and Carraro and Galeotti (1995) investigate policy strategies for increasing environmental cooperation. One proposal includes the option to pay off countries whose net benefits cannot overcompensate net costs. The stability of the agreement is reached by a redistribution mechanism among signatories. Carraro and Siniscalco (1993) and Hoel (1994) study self-financed transfers used to offset free riding. The symmetry of the coalition group can be reached by a system of transfers. They found that strategic behavior may undermine the implementation of side payments. Free riders tend to overestimate economic disadvan-

tages, whereas coalition members could underestimate the initial gains of cooperation.

The USA's free riding position is (among others) a major problem for international climate policy. Game theory suggests that issue linkage may help increase incentives to join a coalition and overcome free riding. The concept of issue linkage has been introduced to abolish potential asymmetries among countries (see Folmer et al., 1993; Cesar and de Zeeuw, 1996). The idea behind this proposal is that countries benefiting from different issues should combine all issues to obtain a stable, symmetric and favorable coalition. Pioneering issue linkage studies are conducted by Tollison and Willet (1979), Haas et al. (1993) and Sebenius (1983). They propose issue linkages with a public good such as the environment, and other issues, e.g. international security and finance. Barret (1995, 1997) proposes linking environmental protection negotiations with trade liberalization. Free riders would have to pay a trade sanction penalty. He finds that the threat of penalties can enlarge the coalition; a grant coalition is therefore hard to obtain. The grant coalition means that coalition where all negotiating parties agree. Carraro and Siniscalco (1995, 1997), and Katsoulacos (1997) propose linking environmental negotiations with increased expenditures in R&D. Technological cooperation is only possible if countries collaborate on environmental issues. Issue linkage could be an incentive for free riders to join a coalition. Issue linkage is based on the idea that, regarding a public good, the benefits of free riding must be offset by the gains of a jointly provided club good. Tol et al. (2000) explore the incentives of joining a coalition by issue linkage through side payments as capital and technology transfer. They find that technology transfer increases the incentive to cooperate. Model results of this study confirm that finding.

The Kyoto protocol allows flexible ways to reach GHG reduction targets. Emissions diminution can be attained through domestic abatement efforts or by international flexible mechanisms like emissions trading between developed nations, investment transfers of energy efficient projects between developed nations (Joint Implementation—JI) or developing nations (Clean Development Mechanisms—CDM). When emissions trading takes place across industrialized countries, the potential main seller of permits will be Russia due to its recent economic slump.<sup>2</sup> Because the USA is the largest greenhouse gas emitter, it will potentially demand a considerable share of emissions permits. The United States' defection induces a reduction in emissions permits demand and therefore the price of permits. This lowers the revenues for permit sellers like Russia

<sup>1</sup>The recent announcement (14.02.02) of the US administration proposes a voluntary environmental program avoiding huge economic losses resulting from economic growth reductions.

<sup>2</sup>This is confirmed by many modeling studies such as those done by Manne and Richels (2001), Den Elzen and de Moor (2001), Buchner et al. (2001), Löschel and Zhang (2002), Kemfert (2002a, b).

and compliance costs for other coalition members like the European Union and Japan. Because of smaller compliance costs, incentives are lowered to invest in climate-friendly technologies. Furthermore, the remaining coalitions run the risk of becoming unstable because of reduced payoffs for Russia, an important player. In order not to lose the economic gains from emissions trading, Russia will try to act strategically by influencing the market price (see, for example, Manne and Richels in this special issue, Löschel and Zhang, 2002). It could bank emissions and sell only part of its emissions permits during the beginning of the first commitment period. The recent negotiation agreement draws from formerly discussed limits on emissions permit trading.<sup>3</sup>

### 3. Game theoretic approach of issue linkage

Emissions reduction is costly for the countries most responsible for climate change. Because of the global character of the climate change problem, each nation could benefit from emissions reductions by other nations. The incentive to reduce emissions in one specific country is very small. This phenomenon is referred to by many authors as a “prisoner’s dilemma” (for example Barrett, 1994, 1998; Carraro and Siniscalco, 1997; Carraro and Hourcade, 1998; Carraro, 1999; Cesar, 1994). However, some countries might have an incentive to create a small or grant coalition<sup>4</sup> to improve net benefits; the game theory of cartel stability mentions this (see Carraro, 1997; Carraro and Siniscalco, 1998; Carraro, 1999). A stable coalition or cartel is characterized by external and internal stability. *Internal stability* means that no country in the coalition has an incentive to leave the cartel. *External stability* implies that no country outside the coalition has an incentive to join the cartel. A cartel is *profitable* if all members of the stable coalition are better off inside the cartel than outside.

We assume that the coalition of emissions reduction nations occurs between  $n$  countries,  $n \geq 3$ , indexed by  $i = 1 \dots n$ ,  $n \geq 3$ . Nations can commit ( $C$ ) or defect ( $D$ ). The collective action is an  $n$ -tuple  $(x_1, x_2, \dots, x_n) \in X^N$  with  $x_i \in \{C, D\} = X_i$  that represents the choice of country  $i$  and  $X^N = X_1 \times X_2 \times \dots \times X_n$ . This can also be written as the pair  $(x_i, x_{-i})$  with  $x_{-i}$  as strategies of all other players except  $i$ . The climate change “prisoner’s

dilemma” signifies:  $u_i(D, \bar{x}_{-i}) > u_i(C, \bar{x}_{-i})$  for all  $i \in N$ . It demonstrates that a rejection always brings a better situation than a commitment. This payoff order has the characteristic that the  $n$  times  $D$  outcome  $(\underbrace{D, D, \dots, D}_n)$  is a single pure strategy Nash equilibrium. Other weak “prisoner’s dilemmas” with more than two players could induce further Nash equilibria (see Lise et al. (2001) for an overview).

The stability analysis of a cartel game is based on the approaches by Carraro (1997, 1999) (Carraro, 1998).  $P_i(s)$  denotes the value for player  $i$  to a member of coalition  $s$ ,  $Q_i(s)$  is the value for player  $i$  not to be a member of coalition  $s$  (see also Kemfert et al., 2003; Lise et al., 2001). Cooperation of one player is reflected as unilateral action. Payoffs of unilateral action are shown as a “no cooperation” scenario in Table 5 (see Appendix A), the payoffs are measured as cumulated consumption values in that specific region. If we consider the cartel game as a normal form game with four players, we can summarize the following payoff<sup>5</sup> matrix:

If no players want to leave the coalition, it is internally stable if  $P_i(s) < Q_i(s|i)$  for all  $i \notin s$ . If no players want to join the coalition, it is externally stable, that is if  $P_i(s \cup i) < Q_i(s)$  for all  $i \in s$ . A coalition is stable if it is both internally and externally stable.

In our analysis we consider four different world regions: the United States of America (USA,1), European Union (EU,2), Japan (JPN,3) and Russia and Eastern Europe (REC,4). As can be seen later in the simulation analysis, the payoff matrix (Table 5) illustrates the different combinations of cooperation and defection games by individual players. Table 1 shows the individual payoffs as a formal game. For example, if the European Union as player 2 does not cooperate, the right hand cell of the first row shows the payoffs ( $P_i(s)$ ) of the cooperating nations one (USA), three (Japan) and four (Russia) as well as the payoff of the non-cooperating nation Europe ( $Q_i(s)$ ). Furthermore, the left-hand cell of the second row demonstrates the payoffs of the nations if player 1 (USA) does not cooperate.

The applied general equilibrium model described below considers eleven total regions. In this analysis, only four regions reduce emissions. The other seven regions play a default strategy of zero emissions reductions. We follow the approach of Carraro and Siniscalco (1997) and Buchner et al. (2002) where countries play a two-stage game. Negotiation countries ( $i = 1, 2, 3, 4$ ) decide first non-cooperatively whether to join a coalition, i.e. the coalition game. Carraro and Siniscalco (1993) call this a “metagame” or a “one-shot” game. In the second stage, they play a non-cooperative, open-loop Nash game to determine their policy

<sup>3</sup>Previous negotiations were influenced by the so-called “supplementarity condition” that any emissions trading should only be supplemental to domestic action. Recent negotiations confirm that there should be no trading limits, although they stress a so-called commitment period reserve, whereby countries must demonstrate via recent inventories that they indeed have made emissions reductions and are not selling credits they are unlikely to have. This would not distort trading, as Babiker et al. (2002) demonstrate.

<sup>4</sup>The grant coalition describes that coalition where all negotiating parties agree.

<sup>5</sup>Payoffs usually mean payments to the individual player, measured in utility values.

Table 1  
Cartel game as formal game with four players

4	3	1	2	Cooperate	Defect
Cooperate	Cooperate	Cooperate		$P_1(1, 2, 3, 4), P_2(1, 2, 3, 4), P_3(1, 2, 3, 4), P_4(1, 2, 3, 4)$	$P_1(1, 3, 4), Q_2(1, 3, 4), P_3(1, 3, 4), P_4(1, 3, 4)$
		Defect		$Q_1(2, 3, 4), P_2(2, 3, 4), P_3(2, 3, 4), P_4(2, 3, 4)$	$Q_1(3, 4), Q_2(3, 4), P_3(3, 4), P_4(3, 4)$
Defect	3	1	2	Cooperate	Defect
	Cooperate	Cooperate		$P_1(1, 2, 3), P_2(1, 2, 3), P_3(1, 2, 3), Q_4(1, 2, 3)$	$P_1(1, 3), Q_2(1, 3), P_3(1, 3), Q_4(1, 3)$
		Defect		$Q_1(2, 3), P_2(2, 3), P_3(2, 3), Q_4(2, 3)$	$Q_1(3), Q_2(3), P_3(3), Q_4(3)$
	Defect	1	2	Cooperate	Defect
		Cooperate		$P_1(1, 2), P_2(1, 2), Q_3(1, 2), Q_4(1, 2)$	$P_1(1), Q_2(1), Q_3(1), Q_4(1)$
		Defect		$Q_1(2), P_2(2), Q_3(2), Q_4(2)$	$Q_1(\emptyset), Q_2(\emptyset), Q_3(\emptyset), Q_4(\emptyset)$

variables. That means (depending on the game’s outcomes in stage one) players decide whether or not to act cooperatively. Issue linkage is considered by the cooperation opportunities of either climate control or technological innovation or trade sanctions against free riders. Because climate change control is a public good, incentives for free riding could only be offset by benefits resulting from technological or terms of trade improvements. R&D investments improve technological innovations that result in improved energy efficiencies. Trade sanctions are imposed on those countries not cooperating on climate control. Incentives to free ride exist only because of potentially positive technology and terms of trade spillover effects. In a formal game, a position  $G$  contains the number  $N$  of players in the game, the possible outcomes  $X^G$  of the game and the related utility functions  $u \equiv \{u_i\}_{i \in N}$ . The following coalition combinations of the game are compared:

with  $P_i(\cdot)$  being the welfare value for nations  $i = USA, EU, JPN, REC$ .  $CC$  denotes Climate Control, and  $IL$  means Issue Linkage. This condition shows that cooperation with the USA is profitable through climate control by emissions reductions and R&D investments triggering energy efficiencies, or trade sanctions against free riders. That means the payoffs to the USA to cooperate need to be higher than the payoffs if the USA would not cooperate on both climate policy and R&D cooperation. This explains the issue linkage incentive for the USA. Furthermore, a coalition between the EU, Japan and Russia regarding both issues would benefit all members if they cooperate only on R&D or trade sanctions:

$$\begin{aligned}
 &P_{EU, JPN, REC} [(USA, EU, JPN, REC)_{CC, IL}] \\
 &> P_{EU, JPN, REC} [(USA, EU, JPN, REC)_{IL}, \\
 &USA_{CC}, (EU, JPN, REC)_{CC}]. \tag{2a}
 \end{aligned}$$

$$G = \left[ \begin{array}{l} \{1, 2, 3, 4\}, \left\{ \begin{array}{l} CCCC, CCDD, DCCD, CCDC, CDDC, CDCC, DDCC, CDDD, \\ DCDD, DDDC, DCDC, DCCC, CCCD, DDDD \end{array} \right\}, \\ \left\{ \begin{array}{l} u(CCCC), u(CCDD), u(DCCD), u(CCDC), u(CDDC), u(CDCC), u(DDCC), u(CDDD), \\ u(DCDD), u(DDDC), u(DCDC), u(DCCC), u(CCCD), u(CDDDD) \end{array} \right\} \end{array} \right].$$

The theoretic conditions necessary for a stable joint coalition is explained below, basically for the free rider country USA. In general, all players have an incentive to free ride on climate control because of the good public character it portrays. Cooperative players can punish non-cooperative players by trade sanctions or excluding technological innovation. Incentives to free ride decrease with issue linkage. Of special interest in this context is the potential cooperative behavior of player 1, the USA. Issue linkage is profitable or rational if the following condition is satisfied:

To make issue linkage reasonable, the USA should undergo cooperation in R&D and improved energy efficiencies only.

$$\begin{aligned}
 &P_{USA} [(USA, EU, JPN, REC)_{CC, IL}] \\
 &< P_{USA} [(USA, EU, JPN, REC)_{IL}, \\
 &(EU, JPN, REC)_{IL}, USA_{CC}]. \tag{2b}
 \end{aligned}$$

The USA would have an incentive to join a coalition on climate control and technological innovation if

$$\begin{aligned}
 &P_i [(USA, EU, JPN, REC)_{CC, IL}] \\
 &> P_i [(EU, JPN, REC)_{CC}, USA_{CC, IL}, \\
 &EU_{IL}, JPN_{IL}, REC_{IL}] \tag{1}
 \end{aligned}$$

$$\begin{aligned}
 &P_{USA} [(USA, EU, JPN, REC)_{CC, IL}] \\
 &> P_{USA} [(EU, JPN, REC)_{CC, IL}, USA_{CC, IL}]. \tag{3}
 \end{aligned}$$

All other Annex I regions would have no incentives to free ride on technological innovation:

$$P_{EU}[(USA, EU, JPN, REC)_{CC,IL}] > P_{EU}[(USA, EU, JPN, REC)_{CC}, (USA, JPN, REC)_{IL}, EU_{IL}], \quad (4)$$

$$P_{JPN}[(USA, EU, JPN, REC)_{CC,IL}] > P_{JPN}[(USA, EU, JPN, REC)_{CC}, (USA, EU, REC)_{IL}, JPN_{IL}], \quad (5)$$

$$P_{REC}[(USA, EU, JPN, REC)_{CC,IL}] > P_{REC}[(USA, EU, JPN, REC)_{CC}, (USA, EU, JPN)_{IL}, REC_{IL}]. \quad (6)$$

To prevent the Annex I regions Japan, Europe and Russia from preferring to cooperate with the USA in technological innovation (and necessarily on climate control), the following conditions must be met:

$$P_i[(EU, JPN, REC)_{CC,IL}, USA_{CC,IL}] > P_i[(USA, EU, JPN, REC)_{IL}, (EU, JPN, REC)_{CC}, USA_{CC}] \quad (7)$$

with  $i = EU, JPN, REC$ .

The following section will investigate whether empirical findings can confirm theoretical conditions. We analyze two different issue linkage proposals. In the first stage of the game, players decide to cooperate or not cooperate on climate control. In the second stage of the game, players not cooperating on climate control are threatened either by the exclusion of technological innovations triggering energy efficiencies or by trade barriers. In this game, revenues from permit trading are reallocated according to previously defined emissions reduction targets. These revenues are used as R&D investments to improve technological innovations.

#### 4. Model description

Empirical validation is based on the applied general equilibrium model WIAGEM. WIAGEM is an integrated assessment model merging an economy model based on a dynamic intertemporal general equilibrium approach combined with an energy market model and climatic submodel covering a time horizon of 50 years incremented into 5-year time steps.<sup>6</sup> The basic idea behind this modeling approach is the evaluation of

market and non-market impacts induced by climate change (see Fig. 1). The model includes an endogenous determination of technological changes. The economy is represented by 25 world regions aggregated into 11 trading regions with each region covering 14 sectors. The sectoral disaggregation contains five energy sectors: coal, natural gas, crude oil, petroleum and coal products, and electricity. The dynamic international competitive energy market for oil, coal and gas is modeled by global and regional supply and demand. The oil market is characterized by imperfect competition with the intention that OPEC regions can use their market power to influence market prices. Energy related greenhouse emissions occur as a result of economic and energy consumption and production activities. Currently, a number of gases have been identified as having a positive effect on radiative forcing (IPCC, 1996) and are included in the Kyoto protocol as “basket” GHGs. The model includes three of these gases: carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous dioxide (N<sub>2</sub>O). These are considered the most influential GHGs within the short-term modeling period of 50 years. Excluding the other gases is not believed to have substantial impacts on the analysis’ insights.

Because of the short-term application of the climate submodel, we consider only the first atmospheric lifetime of GHGs, assuming that the remaining emissions have an infinite lifetime. The atmospheric concentrations induced by energy related and non-energy related emissions of CO<sub>2</sub>, CH<sub>4</sub> and N<sub>2</sub>O have impacts on radiative forcing, influencing potential and actual surface temperature and sea level. Market and non-market damages determine regional and overall welfare development.

In each region, production of the non-energy macro good is captured by an aggregate production function. The production function characterizes technology through transformation possibilities on the output side and substitution possibilities on the input side. In each region, a representative household chooses to allocate lifetime income across consumption in different time periods in order to maximize lifetime utility. In each period, households face the choice between current consumption and future consumption, which can be purchased via savings. The trade-off between current consumption and savings is given by a constant intertemporal elasticity of substitution. Producers invest as long as the marginal return on investment equals the marginal cost of capital formation. The rates of return are determined by a uniform and endogenous world interest rate such that the marginal productivity of a unit of investment and a unit of consumption is equalized within and across countries. Domestic and imported varieties for the non-energy good for all buyers in the domestic market are treated as imperfect substitutes by a CES Armington aggregation function,

<sup>6</sup>The core economic model code was established by Tom Rutherford in 1998. The model has been enlarged by including a 50-year time period, all greenhouse gases, climate change impact assessment, endogenous technological change and issue linkage. The model is written in the computer language GAMS (MPSGE) and solved by the algorithm MILES, see Rutherford (1993). A full model description is given in Kemfert (2003).

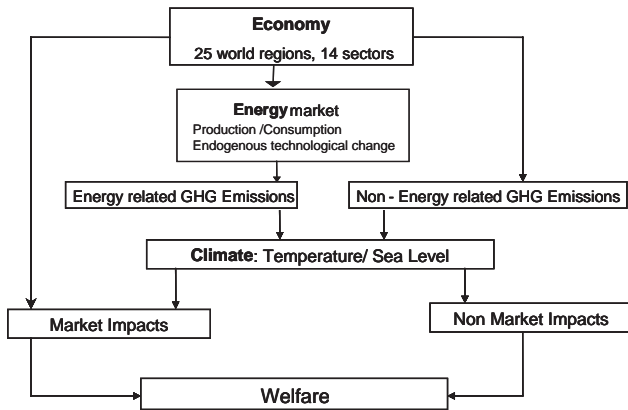


Fig. 1. Welfare determination in WIAGEM.

restricted to constant elasticities of substitution. Emission limits can be reached by domestic action or by trading emission permits within Annex B countries allocated (initially) according to regional commitment targets. Those countries meeting the Kyoto emissions reduction target stabilize their mitigated emissions at 2010 levels.

Goods are produced for the domestic and export market. Production of the energy aggregate is described by a CES function reflecting substitution possibilities for different fossil fuels (i.e. coal, gas, and oil), capital, and labor representing trade-off effects with a constant substitution elasticity. Fossil fuels are produced from fuel-specific resources and the non-energy macro good subject to a CES technology.

*Induced technological change* is considered as follows: energy efficiency is improved endogenously by increased expenditures in R&D.<sup>7</sup> This means that in the CES production function, energy productivity is endogenously influenced by changes in R&D expenditures. The CES production structure follows the concept of ETA-MACRO combining nested capital and labor at lower levels. Energy is treated as a substitute of a capital labor composite determining (together with material inputs) overall output. Energy productivity is increased endogenously by increased R&D expenditures. The incentives to invest in technology innovations are market driven. Because energy efficiency is improved by increased R&D expenditures, emissions reduction targets can be reached with less production drawbacks. Furthermore, investment in R&D and technological innovation gives a comparative advantage. The share of R&D expenditures compared to total expenditures is endogenously determined by production changes. However, this also means that investment in R&D competes with other expenditures (crowding out). Spill over

effects of technological innovations are reflected through trade effects and capital flows. That means that non-R&D cooperating countries developing technological innovations can benefit from spill over effects through trade of technological innovations and capital flows that can be used for R&D investments. Model calculations show that capital flows increase to non-cooperating countries because of improved competitiveness effects and terms of trade effects. This triggers spill over effects regarding technological innovations and energy efficiency improvements through increased R&D investments.<sup>8</sup>

## 5. Model results

This section investigates different climate control coalitions and issue linkage. No cooperation means unilateral action on climate control. Full cooperation incorporates Kyoto greenhouse gas emissions targets by Annex I regions. As mentioned in Section 3, we consider four players: USA (USA), EU (EU), Japan (JPN) and Russia and Eastern European Countries (REC). WIA-GEM considers eleven total regions.<sup>9</sup> In this analysis, only four regions reduce emissions. The other seven regions play a default strategy of zero emissions reductions. We distinguish between Climate Control (CC) scenarios where Annex I permit trade (AT) is allowed or where it is not (NT). Issue linkage is covered by cooperation between induced technological change through increased R&D investments (R&D). A potential punishment for countries not cooperating is concealed through trade barriers (TB).

Table 5 (shown in Appendix A) illustrates the regional payoffs in millions US dollars of all the scenarios and illustrates the cumulated consumption payoffs up to the first commitment period 2012. It demonstrates the individual payoffs of either full or no cooperation of all nations, or individual cooperation combinations. For example, the EUJNREC scenario covers the climate policy cooperation between Europe, Japan and Russia. Unilateral action on R&D investments and energy efficiency improvements can be seen as the current climate control policy of the United States of America. The payoff of this strategy can be found in the payoff matrix of Table 5 in the “no cooperation R&D” USA cell. To compare this strategy with other potential strategies, we must compare the payoff quantity with the payoff values of other scenarios, e.g. the “Full Cooperation” scenario or a cooperative USA strategy

<sup>8</sup> A detailed description of the mathematical interrelations can be found in Kemfert (2002a, b).

<sup>9</sup> Other seven regions are Africa (SSA), Asia (ASIA), China (CHN), Canada (CAN), Latin South America (LSA), Middle East (MIDE) and Rest of the World (ROW).

<sup>7</sup> The theoretical approach is based on Goulder and Mathai (2000); further model applications demonstrate Buonanno et al. (2000) and Kemfert and Tol (2002).

Table 2  
Internally and externally stable coalitions

	CC-NT	CC-AT	R&D	CC-R&D	TB	CC-TB
Internally	$\emptyset$	{USA, EU, JPN, REC} {EU, JPN, REC} {USA, JPN, REC} {USA, EU, REC} {USA, REC} {EU, REC} {JPN, REC}	{EU, JPN, REC} {USA, JPN, REC} {USA, EU, REC} {USA, REC} {EU, REC} {JPN, REC}	{USA, EU, JPN, REC} {EU, JPN, REC} {USA, JPN, REC} {USA, EU, REC} {USA, REC} {EU, REC} {JPN, REC} {EU, JPN}	{EU, JPN, REC} {USA, JPN, REC} {USA, EU, REC} {JPN, REC}	{EU, JPN, REC}
Externally	{USA, EU, REC}	{EU, REC}	$\emptyset$	$\emptyset$	{EU, JPN, REC}	{EU, JPN, REC}
Stable	$\emptyset$	{EU, REC}	$\emptyset$	$\emptyset$	{EU, JPN, REC}	{EU, JPN, REC}

such as the USAJPNREC scenario where the USA, Japan and Russia cooperate. The further explanations refer to the comparison of the individual payoff values among the different cooperation scenarios.

As other model calculations have also demonstrated, meeting emissions reduction targets is costly for those regions facing real emissions reductions, i.e. Europe, USA and Japan. This can be seen if we compare the payoffs of Table 5 where one region does not cooperate, i.e. does not reduce its emissions, with a cooperation scenario. For example, if we compare the USA emissions reduction payoff scenario such as “Full Cooperation” with a no-cooperation strategy of the USA (EUJPNREC scenario), we detect much higher payoffs to the United States (USA) if no emissions reduction takes place. This occurs independent of which “sub scenario” is considered. This means a payoff loss if the United States fully cooperates.

Within the first commitment period, Russia and Eastern European countries benefit from a surplus of emissions permits that can be traded. Because of this, and due to the public good character of climate change described above, countries with binding emissions targets benefit from climate control free riding. Obviously, countries always benefit from a “do nothing” climate control strategy. This is also because we consider only a 50-year time period; significant climate damages that exceed economic benefits occur after this period. However, we intend to assess whether opportunities exist that would allow incentives for cooperation between both climate control and technological improvements. Additionally, it is evaluated whether trade sanctions against non-cooperating countries can lead to cooperative behavior.

Again, we compare the payoffs of the different scenarios to the unilateral, i.e. no cooperation scenario; all numbers are shown in Table 5. All countries with binding emissions targets can profit from emissions trading with Russia.<sup>10</sup> This means the payoff values are

higher in a cooperation scenario with Russia, as found in the EUJPNREC scenario. Unilateral emissions reduction is only profitable if no trading is authorized. Cooperative behavior makes all players better off if emissions permit trading is allowed. Small coalitions benefit cooperating nations with binding emissions reductions targets. Russia as a main seller of permits wants to cooperate with as many potential buying countries as possible. The USA and EU always prefer joining a coalition with Russia if permit trading is allowed. It is profitable for the USA to join a small coalition with Japan and Russia because of reduced compliance costs resulting from lower permit demand and a decreased permit price.

Nations cooperating on technological improvements are better off only if they apply innovations unilaterally. Bilateral trade improves competitiveness effects and increases welfare. The most important outcome of this analysis is the USA’s incentive to cooperate on technological improvements. However, the USA as a free rider on technological innovations could also benefit from spill over effects resulting from technological improvements in cooperating countries. The USA would prefer to join a coalition with Japan and Russia instead of a coalition with both Europe and Japan, as the latter face binding emissions reduction targets. Trade barriers are not significant incentives to join a coalition. Because of the international principal terms of trade effects of strong nations like the USA, Europe and Japan, it seems that trade restrictions against non-cooperating countries is a punishment against themselves. The only exemption is a partial coalition between Japan, Europe and Russia on climate control and trade barriers against the USA. Internally and externally stable coalitions are summarized in Table 2 according to the formal criteria of internal and external stability described above. We find an internally and externally stable coalition where Europe, Japan and Russia cooperate on climate control and apply trade barriers against the USA. However, this small coalition is not profitable, and not all members of the stable coalition

<sup>10</sup>The payoffs for cooperation with Russia are much higher than the payoffs in the “no cooperation”/unilateral action scenario.

are better off inside the cartel than outside of it. This is illustrated by comparing the payoff of the individual members of this coalition with all other payoffs outside this coalition (Table 5). Another externally and internally stable (but not profitable) coalition is the small coalition between Europe and Russia for climate control and potential emissions trading.

Table 3 illustrates the ranking in the payoff matrix explained in the previous section. Because we compare twelve different cooperation scenarios, we rank the utility payoff from 1 to 12. The utilities in the payoff matrix represent the payoff order. We compare the payoff matrices of the five different scenarios.

The payoff rankings are evidence that the USA always benefits from free riding on climate control. However, there is a visible incentive to join a coalition of technological innovations rather than take unilateral action. The USA prefers to join a small coalition on climate control and issue linkage with Europe and Russia instead of Japan and Russia. The reasons for this are stronger terms of trade and competitiveness effects in a coalition with Europe and Russia. However, additional to the “business as usual defect” Nash equilibrium, three other Nash equilibria have the USA, Japan and Russia cooperating on climate control and partaking in emissions trading, climate control and issue linkage of R&D cooperation and pure R&D cooperation without climate control. By ranking all payoffs according to their different coalition options, we summarize the following payoff matrices to show the Nash equilibrium in the shadowed boxes:

Europe prefers to join a small coalition on climate control and issue linkage as well as on technological innovation with the USA and Japan instead of Japan and Russia. However, it is more beneficial for Europe to join a coalition with the USA and Russia. As all coalitions with Russia demonstrate, all countries with binding emissions reduction targets favor a small or full coalition with Russia. Russia offers the supply of permits; the lower the demand for permits, i.e. the fewer the amount of Annex I regions joining the coalition, the lower the compliance costs and the more profitable the coalition is for nations with binding emissions reduction targets. However, if we include stronger assumptions about climatic impacts of climate change due to less stringent emissions reduction targets, benefits of less binding reductions targets always exceed climate change damages. Japan favors joining a coalition on climate control and innovations with Europe and Russia or the USA and Europe instead of Russia and the USA. Japan benefits from technological innovations, and the main trading partners are the USA and Europe.

Cooperating nations invest in R&D investments that improve energy efficiencies. The incentives to invest in R&D expenditures are market driven. To improve

Table 3  
Ranking of payoffs

REC	JPN	USA	EU	Cooperate	Defect
<b>1. CC-NT</b>					
Cooperate	Cooperate	Cooperate	2	7,3,5,11	3,7,9,9
		Defect		9,7,4,2	11,12,1,6
Defect	Cooperate	1	2	Cooperate	Defect
		Defect		6,2,2,10	2,11,6,7
	Defect	1	2	Cooperate	Defect
		Cooperate		Defect	4,1,10,3
		Defect		8,8,8,4	8,8,8,4
<b>2. CC-AT</b>					
Cooperate	Cooperate	Cooperate	2	6,5,8,7	7,7,5,10
		Defect		9,6,7,9	12,11,6,8
Defect	Cooperate	1	2	Cooperate	Defect
		Defect		2,1,1,1	1,12,2,2
	Defect	1	2	Cooperate	Defect
		Cooperate		Defect	11,3,3,4
		Defect		3,2,11,3	4,4,4,5
		Defect		4,4,4,5	4,4,4,5
<b>3. R&amp;D</b>					
Cooperate	Cooperate	Cooperate	2	3,7,8,8	8,9,5,9
		Defect		9,5,6,6	11,11,10,7
Defect	Cooperate	1	2	Cooperate	Defect
		Defect		2,1,1,1	1,12,2,2
	Defect	1	2	Cooperate	Defect
		Cooperate		Defect	10,2,3,3
		Defect		4,3,12,5	5,4,4,4
		Defect		5,4,4,4	5,4,4,4
<b>4. CC-R&amp;D</b>					
Cooperate	Cooperate	Cooperate	2	6,6,8,7	7,7,2,9
		Defect		10,5,5,6	11,11,4,10
Defect	Cooperate	1	2	Cooperate	Defect
		Defect		1,8,7,1	3,12,6,5
	Defect	1	2	Cooperate	Defect
		Cooperate		Defect	12,3,3,2
		Defect		2,1,12,4	4,2,1,3
		Defect		4,2,1,3	4,2,1,3
<b>4. TB</b>					
Cooperate	Cooperate	Cooperate	2	4,12,12,7	8,1,9,10
		Defect		12,8,7,8	11,5,10,9
Defect	Cooperate	1	2	Cooperate	Defect
		Defect		3,7,5,3	6,3,11,4
	Defect	1	2	Cooperate	Defect
		Cooperate		Defect	1,4,6,1
		Defect		1,2,2,3	7,9,8,5
		Defect		7,9,8,5	7,9,8,5
<b>5. CC-TB</b>					
Cooperate	Cooperate	Cooperate	2	7,8,6,7	6,2,10,9
		Defect		12,11,9,4	3,5,12,8
Defect	Cooperate	1	2	Cooperate	Defect
		Defect		9,6,5,1	8,1,11,3
	Defect	1	2	Cooperate	Defect
		Cooperate		Defect	1,4,8,5
		Defect		1,4,9,2	5,10,7,6
		Defect		5,10,7,6	5,10,7,6

competitiveness effects, countries invest in R&D expenditures that advance technological innovations and energy efficiencies. The share of R&D expenditures changes according to production variations.

Table 4  
R&D cooperation scenario: spillover effects of non-cooperating countries in %

	CHN	SSA	LSA	ASIA	MIDE
<i>R&amp;D cooperation</i>					
<i>Full cooperation</i>					
HEV	0.100	0.020	0.030	0.080	0.010
GDP	6.780	0.380	1.480	0.700	1.210
Consumption	9.540	1.660	2.410	7.200	0.660
Energy intensity	-0.030	-0.010	-0.001	-0.010	-0.010
<i>EUJPNREC</i>					
HEV	0.095	0.019	0.029	0.076	0.009
GDP	6.509	0.365	1.421	0.672	1.162
Consumption	8.872	1.544	2.241	6.696	0.614
Energy intensity	-0.029	-0.010	-0.001	-0.010	-0.010
<i>USAJPNREC</i>					
HEV	0.096	0.019	0.029	0.077	0.010
GDP	6.441	0.361	1.406	0.665	1.150
Consumption	8.968	1.560	2.265	6.768	0.620
Energy intensity	-0.029	-0.010	-0.001	-0.010	-0.010
<i>JPNUSAEU</i>					
HEV	0.097	0.019	0.029	0.078	0.010
GDP	6.577	0.369	1.436	0.679	1.174
Consumption	9.063	1.577	2.290	6.840	0.627
Energy intensity	-0.029	-0.010	-0.001	-0.010	-0.010
<i>EUUSREC</i>					
HEV	0.0980	0.0196	0.0294	0.0784	0.0098
GDP	6.6444	0.3724	1.4504	0.6860	1.1858
Consumption	9.3492	1.6268	2.3618	7.0560	0.6468
Energy intensity	-0.0297	-0.0099	-0.0010	-0.0099	-0.0099
<i>USAREC</i>					
HEV	0.092	0.0184	0.0276	0.0736	0.0092
GDP	6.3054	0.3534	1.3764	0.651	1.1253
Consumption	8.6814	1.5106	2.1931	6.552	0.6006
Energy intensity	-0.0279	-0.0093	-0.00093	-0.0093	-0.0093
<i>EUREC</i>					
HEV	0.089	0.0178	0.0267	0.0712	0.0089
GDP	5.9664	0.3344	1.3024	0.616	1.0648
Consumption	8.3952	1.4608	2.1208	6.336	0.5808
Energy intensity	-0.0267	-0.0089	-0.00089	-0.0089	-0.0089
<i>EUUS</i>					
HEV	0.093	0.0186	0.0279	0.0744	0.0093
GDP	6.1698	0.3458	1.3468	0.637	1.1011
Consumption	8.7768	1.5272	2.2172	6.624	0.6072
Energy intensity	-0.0276	-0.0092	-0.00092	-0.0092	-0.0092
<i>JAPUS</i>					
HEV	0.09	0.018	0.027	0.072	0.009
GDP	6.1698	0.3458	1.3468	0.637	1.1011
Consumption	8.586	1.494	2.169	6.48	0.594
Energy intensity	-0.0273	-0.0091	-0.00091	-0.0091	-0.0091
<i>JPNREC</i>					
HEV	0.075	0.015	0.0225	0.06	0.0075
GDP	4.8138	0.2698	1.0508	0.497	0.8591
Consumption	6.5826	1.1454	1.6629	4.968	0.4554
Energy intensity	-0.0213	-0.0071	-0.00071	-0.0071	-0.0071

Table 4 (continued)

	CHN	SSA	LSA	ASIA	MIDE
<i>EUJAP</i>					
HEV	0.089	0.0178	0.0267	0.0712	0.0089
GDP	5.9664	0.3344	1.3024	0.616	1.0648
Consumption	8.4906	1.4774	2.1449	6.408	0.5874
Energy intensity	-0.027	-0.009	-0.0009	-0.009	-0.009

Technological spill over effects are considered through trade effects and capital flows. Technological innovation products are traded internationally. Non-cooperating countries can benefit from spill over effects of technological innovations. Table 4 summarizes the spill over effects of an R&D cooperation scenario for non-cooperating countries. This includes the following regions: Asia (ASIA), China (CHN), Latin South America (LSA) Middle East (MIDE) and Sub Saharan Africa (SSA). The table shows regional GDP, consumption, Hicksian equivalent and energy intensities in percentage changes in comparison to a non-R&D cooperation scenario. Non-cooperating countries can benefit from technological innovation spill over effects that improve energy efficiency. In comparison to no consideration regarding induced technological change, non-cooperating countries can profit through a welfare increase (consumption and GDP). Furthermore, energy intensity in non-cooperating regions decreases due to technological spill over effects; these effects are stronger when more countries cooperate on technological innovation. If economically strong nations like the USA, Europe and Japan are involved in technological innovation cooperation, non-cooperating nations can benefit from more advantageous technology spill over effects due to dominant trade effect terms.

## 6. Conclusion

This paper has examined international climate control coalition games and investigated incentives for cooperation by issue linkage. Two main findings can be summarized. First, there are incentives for a climate control coalition coupled with issue linkage of technological innovations. A full cooperation on climate control and technological improvements benefits all nations in comparison to a unilateral strategy. There is an incentive for the USA to join either a full coalition or a smaller coalition on climate control and technological improvements with Europe, Japan and Russia. Technological innovations improve energy efficiencies, which offer cheaper emissions reduction opportunities. This leads to enhanced competitiveness effects and trade options. If Russia as the main seller of permits joins the coalition, issue linkage becomes most profitable. Trade

Table 5  
Payoffs in millions of dollars by 2010<sup>a</sup>

	JPN	USA	EU	REC
<i>No cooperation</i>				
CC-NT	1,849,719.15	3,438,623.75	3,938,267.81	332,098.39
CC-AT	1,853,643.79	3,451,473.35	3,946,925.08	331,932.03
R&D	1,851,774.91	3,455,640.79	3,942,645.43	331,599.30
CC-R&D	1,856,260.21	3,459,460.95	3,952,594.57	332,497.67
TB	1,840,374.77	3,448,695.06	3,934,686.11	332,065.12
CC-TB	1,850,933.92	3,447,167.00	3,941,053.56	331,366.38
<i>Full cooperation</i>				
CC-NT	1,847,850.27	3,438,137.55	3,929,910.53	330,734.20
CC-AT	1,863,548.83	3,460,597.35	3,947,818.98	332,234.81
R&D	1,871,316.14	3,450,538.79	3,945,221.64	332,209.92
CC-R&D	1,875,681.42	3,464,873.18	3,955,072.78	333,110.02
TB	1,860,529.00	3,446,373.82	3,947,023.05	332,268.08
CC-TB	1,850,279.81	3,455,588.23	3,940,655.60	331,490.61
<i>EUJPNREC</i>				
CC-NT	1,847,663.39	3,563,948.87	3,937,680.58	331,690.80
CC-AT	1,854,668.35	3,571,898.58	3,948,107.33	332,355.59
R&D	1,852,029.03	3,564,876.05	3,943,396.66	331,813.64
CC-R&D	1,858,405.42	3,559,919.18	3,953,051.78	332,910.25
TB	1,840,499.33	3,493,910.29	3,934,944.23	332,270.80
CC-TB	1,850,959.15	3,470,751.21	3,941,176.68	331,492.06
<i>USAJPNREC</i>				
CC-NT	1,848,317.49	3,434,664.68	3,943,839.32	332,522.62
CC-AT	1,853,859.03	3,460,996.47	3,952,196.60	333,221.36
R&D	1,851,899.49	3,463,153.15	3,948,216.95	332,888.63
CC-R&D	1,856,362.57	3,466,613.31	3,958,166.09	333,787.00
TB	1,840,474.33	3,449,053.30	3,932,540.97	333,487.54
CC-TB	1,851,521.37	3,449,715.45	3,935,084.08	332,613.63
<i>JPNUSAEU</i>				
CC-NT	1,845,981.40	3,437,378.52	3,929,512.56	332,730.58
CC-AT	1,846,231.54	3,449,058.12	3,930,399.71	332,031.85
R&D	1,844,529.55	3,449,695.67	3,924,803.07	330,176.05
CC-R&D	1,860,385.46	3,456,336.39	3,962,852.93	330,745.31
TB	1,839,827.54	3,446,238.83	3,934,264.86	332,372.89
CC-TB	1,850,179.68	3,450,292.58	3,940,475.31	329,888.13
<i>EUUSREC</i>				
CC-NT	1,871,211.21	3,437,138.52	3,935,880.01	331,884.16
CC-AT	1,875,135.85	3,461,347.47	3,955,046.31	334,094.78
R&D	1,873,266.98	3,459,856.02	3,946,770.81	333,071.53
CC-R&D	1,877,752.28	3,466,008.18	3,962,839.82	334,660.42
TB	1,830,120.54	3,453,930.91	3,943,138.23	334,227.87
CC-TB	1,838,347.69	3,458,012.23	3,958,564.05	335,159.51
<i>USAREC</i>				
CC-NT	1,870,043.17	3,434,500.50	3,969,085.27	333,063.31
CC-AT	1,873,967.80	3,452,376.30	4,002,466.33	333,762.04
R&D	1,872,098.93	3,456,886.02	3,996,771.28	333,746.71
CC-R&D	1,876,584.23	3,464,882.18	4,003,841.92	334,512.52
TB	1,839,129.56	3,452,376.30	3,934,440.88	333,917.57
CC-TB	1,849,461.56	3,467,291.74	3,938,905.31	334,993.15
<i>EUREC</i>				
CC-NT	1,868,875.12	3,568,877.98	3,937,020.56	332,106.71
CC-AT	1,890,191.91	3,584,047.56	3,953,166.33	332,805.44
R&D	1,881,899.16	3,565,888.20	3,944,237.29	332,011.55
CC-R&D	1,881,581.35	3,547,882.18	3,954,739.82	332,923.51
TB	1,838,922.67	3,447,449.85	3,936,670.36	332,805.44
CC-TB	1,848,785.67	3,443,041.79	3,946,177.79	333,304.54
<i>EUUS</i>				
CC-NT	1,869,843.38	3,435,150.88	3,923,941.04	332,103.51
CC-AT	1,888,230.91	3,451,258.12	3,945,376.83	332,390.78
R&D	1,887,196.14	3,455,153.54	3,940,803.08	332,472.71
CC-R&D	1,887,505.46	3,459,009.74	3,952,353.36	333,371.09
TB	1,827,922.65	3,444,479.81	3,932,538.86	332,269.24

Table 5 (continued)

	JPN	USA	EU	REC
CC-TB	1,836,698.69	3,445,019.75	3,940,928.71	330,953.80
<i>JAPUS</i>				
CC-NT	1,847,573.92	3,434,502.52	3,979,656.23	332,312.51
CC-AT	1,851,495.04	3,445,599.23	4,036,499.32	331,519.78
R&D	1,848,626.66	3,449,662.34	4,032,386.68	331,112.05
CC-R&D	1,858,745.33	3,459,045.70	4,042,069.80	332,711.92
TB	1,841,857.02	3,448,477.54	3,933,440.86	332,007.00
CC-TB	1,856,353.66	3,450,292.58	3,934,179.33	331,142.69
<i>JPNREC</i>				
CC-NT	1,844,571.92	3,597,881.75	4,025,483.04	332,314.67
CC-AT	1,854,111.01	3,611,688.35	4,030,840.31	333,013.40
R&D	1,852,287.15	3,616,482.79	4,032,159.64	332,355.53
CC-R&D	1,857,284.47	3,619,707.95	4,042,051.92	333,186.79
TB	1,841,290.00	3,461,153.29	3,934,427.86	333,013.40
CC-TB	1,856,808.15	3,444,808.77	3,939,808.36	331,626.01
<i>EUJAP</i>				
CC-NT	1,846,505.03	3,599,464.75	3,934,885.10	331,597.27
CC-AT	1,853,231.56	3,610,727.35	3,945,376.85	332,389.53
R&D	1,850,790.66	3,616,121.79	3,938,120.20	332,056.80
CC-R&D	1,856,712.46	3,620,034.95	3,953,436.80	332,955.17
TB	1,840,249.35	3,438,449.83	3,934,538.86	331,956.98
CC-TB	1,850,475.69	3,427,008.75	3,940,641.31	331,956.98

<sup>a</sup> Cumulated discounted consumption by 2010.

barriers against non-cooperating nations are only beneficial if Europe, Japan and Russia create a coalition. This can be explained by the positive welfare effects for the USA as a climate control free rider. Negative competitiveness effects due to trade restrictions on the US economy cannot overcompensate the positive welfare effects of free riding. In total, cooperation on climate control and technological innovation gives stronger incentives to join a coalition than non-cooperating strategies for the majority of nations.

The second main finding from this study shows that there exist incentives for non-cooperating countries to join a coalition by including issue linkage. However, these coalitions are not stable. Only one stable (but not profitable) coalition is reached between Europe, Japan and Russia on climate control with trade barriers against the USA. Europe and Russia could create a stable but small coalition on climate control. Non-cooperating nations can benefit from spill over effects of technological innovation. The more countries cooperate on technological innovation, the stronger these effects will be.

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## Appendix A. Payoffs of climate change coalitions

Table 5 illustrates the regional payoffs in millions US dollars of all the scenarios and illustrates the cumulated consumption payoffs up to the first commitment period 2012.

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