LINKING CARBON MARKETS: A TRADE-THEORY ANALYSIS

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Abstract: Linking emission trading systems (ETS) is a widely discussed option for international cooperation on climate policy after the end of the Kyoto Protocol's obligations in 2012. Benefits are expected from efficiency gains and the alleviation of concerns over competitiveness. However, from trade-theory it is known that due to general equilibrium effects and market distortions, linking may not always be beneficial for all participating countries. Following-up on this debate, we use a Ricardo-Viner type general equilibrium model to study the impacts of *sectoral* linking on carbon leakage, competitiveness, and welfare. By comparing pre- and post-linking equilibria, we show analytically how leakage can arise if one of the 'linked' countries lacks a comprehensive cap on total emissions, although in case of a link across idiosyncratic sectors also anti-leakage is possible. If–as a way to address concerns about competitiveness–a link between the EU ETS and a hypothetical US system is established, the partial emission coverage of the EU ETS can lead to the creation of new distortions between the non-covered domestic and international sector. Finally, we show how the welfare effect from linking can be decomposed into gains-from-trade and terms-of-trade contributions, and how the latter can make the overall effect ambiguous.

Keywords: *Emission Trading, Linking, Trade Theory, Leakage, Competitiveness*

1. Introduction

In view of the expiry in 2012 of the Kyoto Protocol's reduction obligations, the bottom-up linking of existing national or regional emission trading systems (ETS) has become a widely discussed policy option (Buchner and Carraro 2007, Flachsland et al. 2009a, b). For example, the creation of an OECD-wide carbon market that in some way becomes linked to developing countries is now a central pillar of the European Union's climate strategy (EU Commission 2009), in line with various legislative cap-and-trade initiatives in the United States and Australia that have signaled a strong willingness to link their systems (Tuerk et al. 2009).[1] In fact, after COP-15 in Copenhagen did not yield a legally binding multilateral agreement, this approach appears ever more relevant (Stavins 2009).

The merits of international emission trading are well-understood and include efficiency-gains (e.g. Tietenberg 2006), but also the alleviation of competitiveness concerns through the elimination of carbon price differentials and access to cheap abatement options in developing countries (e.g. Alexeeva-Talebi et al. 2008). Some observers, however, have cautioned that in the presence of market distortions and general-equilibrium price effects, the linking of regional emission trading systems may not always be beneficial (Babiker et al. 2004; Anger 2008), and, in addition, might facilitate undesirable international spillovers of shocks in permit markets (McKibbin et al. 2008).[2]

The present contribution follows up on this debate and employs an analytic Ricardo-Viner type general equilibrium model with international trade in goods and fossil fuel resources to study the impacts of sectoral linking on emission leakage, competitiveness, and welfare. The scenarios under investigation are designed to mimic the most important strategic options for permit market links between some of the major players in international climate policy, namely Europe, United States and China.

The EU has specified a comprehensive climate policy package for the time up to 2020, featuring *inter alia* an economy wide emission reduction target to be implemented on one hand by means of the EU ETS–which covers around 40% of European GHG emissions– and on the other hand by various policies and measures aimed at the remaining sectors (European Union 2009a, b). One focus of our analysis is on the potentially adverse impacts such a segmented policy approach may entail. In contrast, if the United States were to implement a climate policy package along the lines of the Waxman-Markey draft, its economy-wide cap-and-trade system would cover about 85% of US greenhouse gas emissions (Larsen and Heilmayr 2009). For China we analyze scenarios representing the implementation of a scaled-up Clean Development Mechanism or sectoral trading scheme (EU Commission 2009, Schneider and Cames 2009), but we also take into account the possible simultaneous presence of an economy-wide intensity target.[3]

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[1] OECD regions preparing the implementation of cap-and-trade systems include the United States, Australia, Japan, South Korea, as well as individual US states and Canadian provinces organized in the Western Climate Initiative (WCI) or Midwestern Greenhouse Gas Reduction Accord.

[2] For a review of merits and demerits of linking cap-and-trade systems, see, e.g., Flachsland et al. (2009b).

[3] Prior to the COP-15 meeting at Copenhagen, China announced its intention to reduce the carbon intensity of its economy by 40-45% from 2005 to 2020.

By comparing the pre- and post-linking equilibria between two countries, we find that leakage can arise if one of the ‘linked’ countries lacks a comprehensive cap on its total emissions. In this case, an increased uptake of fossil fuel resources in the non-capped sector would be observed. However, whether or not leakage actually occurs turns out to depend on which industries are linked in the joint permit market: if their respective output goods are imperfect substitutes, leakage does not occur or may even become negative (what we call anti-leakage). As an extension of this analysis, one mechanism that is shown to be ineffective as a means to prevent leakage is an economy-wide intensity target, which has recently been discussed as a politically more feasible option than an absolute cap, at least for developing countries.

If the EU ETS was to establish a link with a hypothetical US system, leakage would not be an issue because both regions would face a limit on total emissions. Besides gains-from-trade, a major driver for implementing such an option would be to address concerns about competitiveness, i.e. the idea of harmonizing permit prices in order to ‘level the carbon playing-field’ (Houser et al. 2008). However, our results indicate that due to the EU ETS’ partial coverage of total EU emissions, this can only be achieved to a limited extent. As will be shown, under such circumstances linking can create (or increase) a distortion both between the EU’s own sectors as well as between the EU’s non-ETS sector and its US counterpart.

Finally, our analysis provides an explicit representation of the welfare effects of linking in a general-equilibrium setting. Namely, the overall effect is decomposed into an always positive gains-from-trade and a terms-of-trade effect. Because the sign of the latter depends on which goods a country exports and imports, the net effect turns out to be ambiguous.

The remainder of this article is organized as follows: The next section reviews the relevant literature. Section 3 sets out our model. Results are derived and discussed in Section 4 and–for the special case in which one good becomes non-traded–in Section 5. Section 6 concludes.

2. Literature Review

Studies on linking different emission trading systems can roughly be divided into three categories: (i) qualitative-institutional studies, (ii) game-theoretic approaches, and (iii) numerical partial and general equilibrium analyses.

The first category contains a number of studies which have investigated the institutional aspects involved in linking, focusing on the different systems’ design compatibility as well as qualitative economic and political impacts (e.g. Sterk et al. 2006, Tuerk et al. 2009, Flachsland et al. 2009a,b). They mainly provide detailed analyses of proposals for new cap-and-trade systems, identify needs for harmonization of system design features, or compare different institutional arrangements for the governance of joint carbon markets. However, due to the nature of these studies, the scope for economic analysis remains rather limited.

The second strand of more game-theoretic research focuses on strategic interactions between countries that unilaterally implement domestic trading systems and consider linking, i.e. international emission trading, as a policy option. Helm (2003) provides evidence that in such a case the anticipation of linking creates an incentive for low-damage countries to relax their cap in order to benefit from increased permit sales. Rehdanz and Tol (2005) discuss suitable instruments, in particular import quotas, which enable buyers to contain such inflationary tendencies on the sellers' side. Carbone et al. (2009) employ a computable general equilibrium (CGE) framework with international trade in goods, resources, and permits, and allow countries to anticipate the impact of their quota allocation decision. They identify the possibility of oligopolistic behaviour, i.e. that the incentive of net permit sellers to raise permit prices by increasing the stringency of their cap may outweigh their incentive to relax the cap, especially in the presence of additional positive effects on international resource markets.

Finally, with a focus on the internal dynamics of the EU ETS, Dijkstra et al. (2008) as well as Böhringer and Rosendahl (2009) analyze the partition between ETS and non-ETS sectors as a strategic game of EU countries against each other, constrained by the fixed EU ETS total emission cap. While the former specify the conditions for welfare gains and losses when additional trading sectors enter the system, the latter pursue an empirical analysis and find evidence for a strong role of political economy forces.

In the third group of studies, partial equilibrium analyses of permit markets using regionally and sectorally specified marginal abatement cost curves allow studying the impact of carbon market linkages on allowance prices and regional abatement costs (Anger 2008, Anger et al. 2009, Stankeviciute et al. 2008, Russ et al. 2009). One main conclusion to draw from partial market modeling is that unless linking is assumed to be accompanied by the introduction of severe market distortions, it will be welfare enhancing for all countries due to the standard gains-from-trade effect (Anger 2008, Anger et al. 2009). Linking cap-and-trade systems to the CDM offers particularly high efficiency gains due to the expected large supply of low cost abatement options in developing countries. However, by definition these models ignore the general equilibrium effects of permit trade, e.g. a loss of competitiveness or carbon leakage occuring due to changes in relative prices.

To capture such effects in the context of climate policy, several CGE models were developed and first applied to assess the economic implications of the Kyoto Protocol (e.g. Bernstein et al. 1999, McKibbin et al. 1999) and, more recently, the impacts of bi- and plurilateral linking. For example, Babiker et al. (2004) and Paltsev et al. (2007) show that an increase in the domestic price of carbon after joining international emission trading can reinforce pre-existing distortions associated with inefficiently high fuel taxes – up to the point where the corresponding welfare losses outweigh the primary gains in efficiency from emission trade. Most closely related to our work–in terms of the issues addressed–is Alexeeva-Talebi and Anger (2007) and Alexeeva-Talebi et al. (2008): the first study finds that whenever linking the EU ETS to another country's system leads to an inefficient emission allocation between ETS and non-ETS sectors in the latter (assuming perfectly efficient policies in the no-linking case), the link is welfare decreasing for the EU partner country and has hardly any impact on EU welfare. The subsequent study analyzes the competitiveness impacts on the EU economy from unilateral climate policy, and finds them to be largely negligible if the EU ETS establishes a link with the CDM market, due to the resulting much lower allowance price. However, because of the numerical character of CGEs, such analyses can only provide limited insights on the underlying mechanisms at work, which is the objective of our contribution.

Thus, our study aims to complement previous contributions through its analytical general equilibrium framework based on trade-theory. This allows for a theoretical investigation into the economic and environmental impacts of linking carbon markets, taking into account the interplay of permit trade and trade in sectorally differentiated goods and fossil fuel resources. In that sense, our adoption of a trade-theory point of view follows the work of Copeland and Taylor (2005), although–differently from us–they used a long-run oriented Heckscher-Ohlin framework and focused on the strategic effects of trade in a model with endogenous emissions choice.

3. Model Definition and Country Specification

Model definition

We consider an extended Ricardo-Viner model with two countries, home *h* and foreign *f* (index *i*), as main protagonists, and an additional country *s* as supplier of fossil fuel resources *R*, which are an essential input factor for production in both *h* and *f*.

Each country's economy is composed of two sectors, producing goods *X* and *Y* (index *j*).[4] The corresponding constant-returns-to-scale technologies, *F* and *G*, use fossil fuel resources as well as other inputs–such as capital and labor–for production. We adopt the short- to mid-term point of view of the Ricardo-Viner (or specific factor) model (Mayer 1974, Neary 1978)[5], assuming the fossil fuel resource as being perfectly mobile across sectors, while the other inputs are sector-specific and hence immobile in the short- to medium-run. Thus, they are implicitly included in the specific functional forms of *F* and *G* without the need to explicitly write them down as arguments:

$$(1) \qquad X^i = F^i(R_X^i) \qquad\qquad Y^i = G^i(R_Y^i) \quad ,$$

with strictly concave functions F^i and G^i (declining returns for each individual production factor), and $R_X^i + R_Y^i = R^i$ capturing the sectoral allocation of resource inputs in country *i*.

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[4] The resource supplier's production of *X* and *Y* is supposed to be negligibly small.

[5] This approach has the merit of avoiding the tendency towards full specialization that arises in a Heckscher-Ohlin model when factors become traded (Markusen 1983).

Emissions are assumed to be identical with the amount of fossil fuel resources employed in production; the two terms are therefore used interchangeably throughout this article.

In view of the symmetry of the problem, we choose the resource as the numeraire (i.e. p_R=1), and p_x and p_y as the price of good *X* and *Y*, respectively.[6] Firms in each country maximize profits under perfect competition and hence satisfy the usual first-order conditions for the marginal product of the resource input:

$$(2) \qquad 1 = p_x \, F_R^i(R_X^i) = p_y \, G_R^i(R_Y^i)$$

where the subscript *R* is used to denote the derivative with respect to *R*, i.e. the marginal product. Note that as payments accrue to the other (immobile) factors of production, the value of output of *X* and *Y* exceeds the value of the resource used in their production, even though firms do not have market power. Inverting Eq.(2) allows obtaining the resource demand function of country *i*:

$$(3) \qquad R^i = F_R^{i\,inv}(p_x) + G_R^{i\,inv}(p_y)$$

In line with the short-run focus of this analysis, we ignore potential changes in the environmental damage level resulting from variations in the amount of fossil fuel combustion (i.e. emissions).[7] That is, in our model consumer preferences are represented through a utility function *U* which only depends on the realized consumption bundle $U = U(C_x^i, C_y^i)$. Furthermore, we assume that tastes are homothetic and uniform across countries. Thus, taken prices as given, all consumers spend the same fraction η of their income I^i on good *X* and $1-\eta \equiv \tilde{\eta}$ for consumption of good *Y*, where η depends only on the parameters of the utility function and the relative price between goods, which for convenience we denote in shorthand form by $p_{x/y} \equiv p_x / p_y$. Demand for good *X* and *Y* in country *i* is thus given by, respectively, $\eta \, I^i / p_x$ and $\tilde{\eta} \, I^i / p_y$. Welfare can be expressed as a function of real income using the indirect utility function:[8]

$$(4) \qquad W^i = U\left[\frac{I^i}{\phi(p_x, p_y)}\right]$$

where ϕ is the exact price index of consumption goods. Finally, we assume that the resource supply side can be characterized by a supply function *S*

$$(5) \qquad R = S[\phi(p_x, p_y)] \quad ,$$

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[6] While usually one of the goods is chosen as the numeraire, our choice preserves the symmetry between *X* and *Y* and thus allows for a more intuitive presentation of the results.

[7] Climate change is a stock pollutant problem with a significant delay between emissions and damages.

[8] We sometimes use brackets [..] to emphasize the argument of a function.

that is strictly decreasing in ϕ. Using R as the numeraire, its nominal price remains constant. Supply, however, is determined by its real price, i.e. the nominal price divided by the price index ϕ. As rising goods prices decrease the real price of R, its supply is negatively related to p_x and p_y. Such a functional form can be derived by assuming either that (i) resource extraction is associated with increasing social costs (e.g. disutility from supplying labor), or (ii) goods X and Y are necessary inputs for the extraction of R,[9] or (iii) there is a tendency of forward-looking extractors to postpone extraction in the face of falling resource prices.

To summarize, in this model a global competitive equilibrium is defined by prices p_x and p_y such that (i) firms maximize profits, i.e. Eq.(2) is satisfied in both countries, (ii) consumers maximize utility, i.e. their demand is determined by the function η, (iii) each country's income I^i equals its GDP (corresponding to the factor income of the non-resource inputs, e.g. labor), i.e.

$$(6) \qquad I^i = p_x X^i + p_y Y^i - R^i \quad ,$$

(iv) world markets for goods clear, i.e.

$$(7) \qquad \frac{\eta(p_{x/y})}{p_x}\left(I^h + I^f + I^s\right) = X^h + X^f \text{ and } \frac{\tilde{\eta}(p_{x/y})}{p_y}\left(I^h + I^f + I^s\right) = Y^h + Y^f$$

and, finally, (v) the competitive resource market clears, i.e.

$$(8) \qquad S\left[\phi(p_x, p_y)\right] = R^h(p_x, p_y) + R^f(p_x, p_y) \ .$$

Eq.(8), together with the four independent conditions implied by Eq.(2), and the equation obtained by dividing through the market clearing conditions from Eq.(7) form a set of six equations allowing to uniquely determine the six independent variables p_x, p_y, and R_j^i, from which–by using $\eta(p_{x/y})$–the individual consumption levels follow directly. Note that combining Eq.(6) and Eq.(7) implies that trade is always balanced, as the value of consumed goods must by definition equal national income.

Any trade equilibrium will comprise flows of resource R from s to h and f, and flows of goods X and Y towards s, as well as–possibly–an exchange of Y and X between h and f. For example, the production functions of h and f could be strongly asymmetric, such that h produces almost only good X, and f almost only good Y. In this case both countries would trade with the resource supplier but also with each other. On the other side, if h and f are perfectly symmetric, they will still trade with the resource supplier but not with each other. In other words, the home and foreign country will always be net exporters of either Y or X, or of both.

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[9] We thank Gabriel Felbermayr for this suggestion.

Country specification

The model has the aim to provide a stylized representation of the climate policies of the United States, Europe, and China. For the case of the United States we assume the adoption of the Waxman-Markey Bill as described in Larsen and Heilmayr (2009). Europe has already adopted a comprehensive climate policy package (European Union 2009a,b), and China is assumed to implement a scaled-up CDM or sector-based trading mechanism (EU Commission 2009), possibly on top of its currently proposed economy-wide intensity-target.

The Waxman-Markey cap-and-trade system would cover 85% of US (here denoted as '*f*') greenhouse gas emissions and can therefore be modeled as an economy-wide cap-and-trade system with an upper bound $\overline{R}^{f}$ on national emissions.[10] As a consequence, this policy always leads to an efficient domestic sectoral burden sharing of the abatement effort, which in formal terms means that in both sectors the same gap arises between the value of the marginal product and the (normalized) world price of the resource:

$$(9) \qquad p_x\, F_R^f(R_X^f) = p_y\; G_R^f(\overline{R}^f - R_X^f) > 1 \quad ,$$

Due to the policy-prescribed limit on national resource intake, the market clearing condition for the global resource market from Eq.(8) simplifies to

$$(10) \qquad S[\phi(p_x, p_y)] = \overline{R}^f + R^h(p_x, p_y) \quad .$$

In Europe ('*h*'), the EU ETS encompasses only 40% of all GHG emissions.[11] To model this case of a far more limited coverage of the trading system, we assume one sector, say *X*, to be the cap-and-trade sector with a given upper limit $\overline{R}_X^h$ on the resource intake, while the other sector, *Y*, is regulated by an adjustable command-and-control policy or resource tax τ_y.[12] Constraining the production in sector *X* by a fixed absolute resource cap $\overline{R}_X^h$ implies for the marginal product in this sector

$$(11) \qquad p_x\, F_R^h(\overline{R}_X^h) > 1 \quad .$$

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[10] Sectors not covered by the cap-and-trade system envisaged by Waxman-Markey are: (i) sources below the ETS compliance threshold, (ii) land-use and land-use change, (iii) landfill gases, (iv) HFC, (v) CFCs, (vi) nitrous oxide from nitric acid plants, and (vii) coal mine methane emissions. Given that sectors (ii) to (vii) do not use fossil fuel resource inputs, we assume them to be negligible in the context of our analysis.

[11] The major non-covered sectors are road transport and heating fuels.

[12] The European Union aims at a 20% economy-wide emission reduction relative to 1990 by 2020. Since the policy package allows the use of CDM credits in order to achieve the envisaged reductions for the non-ETS sectors (European Union 2009a), one may argue that a crediting mechanism should also be incorporated in our model. However, since there is a comparatively low 3% limit on CDM use in the non-ETS sectors, and a total reduction target of 10% below year 2005 emission (EU Commission 2008), we assume that domestic policies–here represented by an emission tax–will nevertheless be the principle means for meeting the objective.

The other sector's resource intake can then be viewed as being subjected to a tax τ_y^h

$$(12) \qquad p_y\; G_R^h(R_Y^h) = 1 + \tau_y^h \quad ,$$

which is set in a way to ensure that the resource demand of sector Y always stays at the level needed for compliance with the economy's overall emissions cap: [13]

$$(13) \qquad G_R^{h^{inv}}\left(\frac{1+\tau_y^h}{p_y}\right) \overset{!}{=} \overline{R}^h - \overline{R}_X^h \qquad \Rightarrow \quad \tau_y^h = p_y\; G_R^h(\overline{R}^h - \overline{R}_X^h) - 1 \quad .$$

The market clearing condition in the resource sector is the same as in the case above for the United States, Eq.(10). However, since in this case the internal burden-sharing between sectors may not be efficient, a representation of the equilibrium in terms of allowance price (or implicit resource tax) τ_x^h and emission tax τ_y^h must be written in a sector-wise differentiated way as

$$(14) \qquad S[\phi(p_x, p_y)] = R_X^h(\tau_x^h, p_x, p_y) + R_Y^h(\tau_y^h, p_x, p_y) + R^f(p_x, p_y) \quad .$$

China and other developing countries currently reject binding economy-wide emission caps, but might implement crediting mechanisms modeled on the Kyoto Protocol's Clean Development Mechanism (CDM). Since the current project-based CDM approach is plagued by doubts over additionality (Schneider 2007) and lack of scale (Stern 2008), several suggestions have been made on how an upscaling could be achieved. These include proposals for absolute or intensity-based no-lose crediting baselines for emissions on a sectoral level, and policy or programmatic approaches that bundle projects in order to reduce transaction costs (EU Commission 2009, Schneider and Cames 2009).

Within our model, these approaches are equivalent since all imply the setting of a sectoral cap against which emission reductions are credited. Hence, we represent this mechanism by an absolute sectoral business-as-usual (BAU) cap $\overline{R}_j^f$ for sector j, while the other sector faces no resource constraint. Since the presence of such a crediting mechanism implies that the affected sector faces an additional opportunity cost when using the resource input, it leads to the same first-order condition for the marginal product that holds for the EU ETS sector in Europe, Eq. (11). The difference to the European policy case is the absence of an economy-wide reduction target and corresponding resource tax (or command-and-control policy) for the non-ETS sector.[14]

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[13] The tax is assumed to be recycled back to households via lump-sum transfer. Note that for the purpose of our analysis, there is no need to include the tax receipts in Eq.(6) or elsewhere, since they have no influence on the country's total income, which only depends on its GDP measured in international prices.

[14] Another difference consists in the non-binding character of the business-as-usual cap, which, however, is irrelevant in a model without uncertainty like ours.

Although China's position on the non-acceptance of a binding absolute emission target has remained firm, its government recently announced that it plans to reduce the carbon intensity of the national product (i.e. CO_2 emissions per unit of GDP) by 40 – 45% below its 2005 level by the year 2020. If implemented, any type of crediting mechanism would operate in parallel to this domestic intensity policy. In our model, this can be represented by introducing the additional constraint

$$(15) \qquad \overline{R}^{f}(\overline{\gamma}) = \overline{\gamma}\, I^{f} \quad ,$$

where $\overline{\gamma}$ represents the policy-imposed intensity level.

4. Economic Impacts of Linking

Focusing on the linking options from the point of view of the European Union towards the United States and China, we analyze the following linking scenarios in terms of their economic and environmental consequences (leakage), and discuss impacts on competitiveness and welfare:

1. EU ETS and sector X in China
2. EU ETS and sector Y in China
3. EU ETS and sector X in China, with China under national intensity target
4. EU ETS and economy-wide United States ETS

Case 1: EU ETS and China link along X-sectors (symmetric link)

The European Union officially envisages a link of its EU ETS to sectoral crediting schemes in major developing countries such as China (EU Commission 2009, Russ et al. 2009). In this scenario, we consider economic impacts of linking the European trading scheme ('home') to sectors in China ('foreign') that are symmetric to those covered by the EU ETS, i.e. power generation and a number of emission intensive industries such as iron and steel, aluminum, and cement production.

Proposition 1: *Let the home country be fully capped at* $\overline{R}^{h}$*, with an ETS in sector X holding* $\overline{R}_x^{h}$ *permits, and an adaptable emissions tax* τ_y^{h} *in sector Y that ensures a constant intake* $\overline{R}_y^{h}$*. If the foreign country adopts a sectoral BAU target* $\overline{R}_x^{f}$ *for its X-sector in order to establish an emissions-trading link with home's X-sector ('linking'), then*

- (i) *the price* p_x *of good X falls,*
- (ii) *the price* p_y *of good Y rises,*
- (iii) *the resource R appreciates in real terms,*
- (iv) *the resource intake (=emissions) in foreign's Y-sector increases, i.e. leakage occurs, and*
- (v) *the emission tax* τ_y^{h} *must rise.*

Proof: See Appendix A.1

When foreign implements a BAU cap[15] for its *X*-sector and links with home's ETS, the joint output of the two *X*-sectors rises to its efficient level. In order to absorb the increased global supply of good *X*, its price p_x must fall. But due to the homothetic preferences, consumers now also have a higher demand for good *Y*, leading to an increase in its price and creating an incentive to expand its production in foreign's uncapped sector *Y*, which causes linking-induced leakage. Because firms' incentive to produce good *Y* also increases in the home country, the corresponding resource tax τ_y^h has to be increased in order to keep the resource intake constant. For a segmented system like the EU's, this means that if the 'price of carbon' was initially equalized across trading and non-trading sectors, this will no longer be the case after linking, since the latter leads to a reduction of the permit price in home's sector *X*, and at the same time to a higher fossil resource tax in sector *Y*.

In terms of welfare, there are several effects of linking that must be taken into account: the direct effect from emission trading, the terms-of-trade effect due to changes in p_x and p_y, and the expansion of foreign's *Y* sector, although in a marginal analysis the latter does not contribute. As said before, we also ignore the long-run negative environmental effects associated with a short-term increase in fossil fuel usage.

Proposition 2: *Under the conditions of symmetric linking described in Proposition 1, the marginal change in welfare for home and foreign is given by*

$$(16) \qquad dW^i = \frac{U'}{\phi}\left(p_x\, dX_T^i + \left(X^i - C_x^i\right)dp_x + \left(Y^i - C_y^i\right)dp_y\right) \quad ,$$

where X_T^i *denotes country i's increase in available X-goods due to gains-from-trade. It is ambiguous whenever country i is a net exporter of good X or a net importer of good Y, or both. On the other hand, it is always positive for the resource supplier country.*
Proof: See Appendix A.2

Linking leads to an increase in the joint output of *X*-goods. Dividing the achieved surplus between the two countries gives the expected positive gains-from-trade effect for both home and foreign, the first term in Eq.(16). However, the terms-of-trade effect embodied in the next two terms turns out to be ambiguous, possibly leading to a loss of income and welfare. Depending on the functional specification of the production function, the home country may be a net exporter of both or of only one good (e.g. if home and foreign are ex-ante symmetric it will export both goods). Clearly, if home is a net exporter of good *X,* or a net importer of good *Y* (or both), then the linking-induced fall of p_x and rise of p_y can lead to an overall loss of welfare due to linking. The same reasoning applies to the foreign country. In fact, because changes in the terms-of-trade represent a zero-sum-game

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[15] We focus on a BAU cap since in the context of a sectoral link with a developing country this appears to be an empirically relevant case. However, our results from Propositions 1,2,3 and 6 also hold if country 'f' has already implemented a more stringent sectoral cap before joining the linking agreement.

at the global level, and because the supplier country always improves its position (the resource becomes more expensive in real terms, otherwise supply would not increase), home's and foreign's combined terms-of-trade effect is negative, meaning either that one of them benefits and the other loses, or otherwise that they both lose.

Therefore, in the present scenario of symmetric linking the resource supplier is the only guaranteed winner. Home and foreign both realize efficiency gains, the distribution of which will depend on the functional specification of the production functions. With regard to terms-of-trade, no more than one of the two countries can benefit, which–in the face of a falling price for good *X* and a rising price for good *Y*–will be the country that is relatively more specialized in the production and export of good *Y*. For larger, non-marginal changes, the foreign country also benefits from the expansion of its *Y* sector, a possibility from which the home country is excluded.

Case 2: EU ETS and China link between X and Y sector (asymmetric link)

In view of the previous analysis, a natural question is to ask whether it would make any difference if the link between the EU ETS and Chinese sector is established in an anti-symmetric manner, i.e. from sector *X* in the European Union to sector *Y* in China. The following proposition confirms that this is indeed the case:

Proposition 3: *If, under the same conditions as in Proposition 1, the link for emission trading is established between sectors X in the home and Y in the foreign country, then*

- *(i) the price p_x of good X falls,*
- *(ii) the price p_y of good Y rises,*
- *(iii) the resource R depreciates in real terms,*
- *(iv) global resource intake (=emissions) is reduced, i.e. negative leakage occurs, and*
- *(v) the emission tax τ_y^h must rise.*

Proof: See Appendix A.3

In principle, asymmetric linking produces the same kind of effects as symmetric linking: sector *X* in the home country imports 'emission permits' and expands, thereby increasing the world supply of good *X* and inducing a fall of p_x. The difference is that foreign has to reduce the output of *Y* in order to enable the profitable generation and sale of credits to home's capped sector *X*. In this case the fall of p_x gives foreign's *X* sector an incentive to reduce its production and, hence, its usage of resources. This reduction in both of foreign's sectors–while emissions remain controlled at the 'cap-plus-credits' level in the home country–leads to what may be termed 'anti-leakage'.

In practical terms this scenario may represent a hypothetical sector crediting mechanism implemented in China's transport or heating sector, which on the one hand would induce cost-effective emission reductions in these sectors, and on the other lead to lower European Allowance (EUA) prices in the EU ETS. European ETS industries will expand their production in the presence of lower EUA prices, thereby lowering world prices for these products, with the effect of crowding out some industrial production in China.

Hence, from an environmental perspective an asymmetric linking to crediting schemes appears preferable to a symmetric one, since it avoids the leakage effect discussed before. However, as in the symmetric case the rise of p_y necessitates an increase in the fossil resource tax τ_y^h at home, which can aggravate distortions stemming from the different values of the marginal resource product in home's *X* and *Y* sectors. Finally, Proposition 2 also remains valid in terms of the linking-induced changes of the two countries' welfare, except for the resource supplier, who now experiences a negative terms-of-trade and welfare effect.

Case 3: Symmetric link between EU ETS and China, with intensity target in China

In the run-up to COP15, the Chinese government announced its intention to unilaterally reduce the carbon intensity of China's national product (CO_2 emissions per unit of GDP) by 40 to 45 percent below the year 2005 level. In view of the possibility for symmetrical sectoral links to induce leakage discussed in case 1, the question arises of whether the implications of Proposition 1 could be averted if China's total emissions are constrained by an intensity target, or, in other words, whether or not an intensity target could serve as a safeguard mechanism against unintended leakage. To assess this question, we consider a symmetric link between the *X*-sectors of home and foreign just as in case 1, but assume that in addition a binding but not too stringent (to ensure foreign is an exporter of permits) intensity target for total emissions is implemented in the foreign country.[16]

Proposition 4: *Let home's total emissions be capped at* $\overline{R}^h$*, with an ETS in sector X endowed with* $\overline{R}_x^h$ *permits, and an adaptable emission tax in sector Y. Furthermore, assume foreign's total emission level to be constrained by a binding intensity target* $\overline{R}^f = \overline{\gamma} \cdot I^f$*, which, however, implies a lower emission price than in home's ETS. In order to establish an emission trading link with home's X-sector, resource use in foreign's X-sector now becomes capped at its pre-linking level* $\overline{R}_x^f$*. An adaptable emission tax is levied in foreign's Y-sector to ensure compliance with its intensity target. In this case,*

- *(i)* *the price* p_x *of good X falls,*
- *(ii)* *the price* p_y *of good Y rises, and*
- *(iii)* *resource intake (=emissions) in foreign's Y-sector can increase or decrease (i.e. positive or negative leakage), depending on the net effect of linking on foreign's GDP.*

Proof: See Appendix A.4

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[16] There is no need to discuss output-based sectoral intensity targets, i.e. limits on the emissions per unit of sector output. In our framework the choice of production technologies is fixed in the short-term, and hence an absolute cap $\overline{R}_x$ in the *X*-sector is fully equivalent to a sectoral intensity target of $\overline{\gamma}_x = \overline{R}_x / F(\overline{R}_x)$.

As in case 1, linking home's ETS to foreign's less strongly constrained *X*-sector results in an efficiency-enhancing reallocation of resource inputs to the home country, raising the global output of *X* while keeping the combined resource use of both countries' *X*-sectors constant at $\overline{R}_x^h + \overline{R}_x^f$. As a consequence of the increased supply of good *X*, good *Y* will become relatively more expensive, creating an incentive for firms in both countries to increase their production of *Y*.

The difference to the standard symmetric linking of case 1 is that in presence of a binding intensity target, foreign's *Y*-sector cannot expand unless its GDP has grown due to linking. Under an intensity target, the allowed emission level is proportional to GDP, meaning that any additional emissions would exceed the target unless GDP has grown. As discussed before, gains-from-trade in the *X*-sector in combination with the ambiguous terms-of-trade effect due to the changing prices p_x and p_y mean that foreign's GDP might be both higher or lower than in the no-linking case. Therefore, positive or negative leakage equal to the intensity target times the change in foreign's GDP occurs, demonstrating that the intensity target cannot substitute a comprehensive absolute emissions cap as an effective safeguard against leakage.[17]

Case 4: Link between EU ETS and United States ETS

This scenario involving two fully capped systems can be interpreted as a stylized representation of a hypothetical link between the current EU ETS and a Waxman-Markey like US system. One would expect the US to become a net exporter of permits in this case, given that the EU Commission (2008) expects a year 2020 EU allowance price of 30€/tCO_2, while a study by the EPA (2009) suggests a lower price of about 16\$/tCO_2 for US allowances. Besides efficiency gains, the main motivation for such a linking project would be to harmonize the price of emissions across regions and thereby address the issue of competitiveness. Because both regions have binding national emission targets, there is no concern with regard to leakage in this case. However, the fact that the EU's policy is built on an internal segmentation with a trading and non-trading sector gains particular relevance.

Proposition 5: *Let foreign have an economy-wide cap-and-trade system and home a cap on total emissions implemented through a sectorally segmented policy, with an ETS in the X-sector and an adaptable emission tax* τ_y^h *in the Y-sector. Suppose the (implicit) price of emissions in home's two sectors is initially the same, and higher than in the foreign country. If the two countries establish a link between foreign's ETS and home's X-sector,*

- *(i)* *the price* p_x *of good X falls,*
- (ii) *the price* p_y *of good Y rises,*
- (iii) *the permit price in home's X-sector decreases, while the emission tax in its Y-sector must increase, and*

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[17] We do not consider the case of asymmetric linking with an intensity target. As we have demonstrated in case 2, asymmetric linking leads to negative leakage. In this case, an additional 'emissions per GDP' intensity target would simply become non-binding and hence irrelevant.

(iv) *the emission tax differential between home's and foreign's Y-sector may become greater (competitiveness), e.g. if foreign's post-linking output of Y has increased with respect to the pre-linking level.*

Proof: See Appendix A.5

The proposition shows that linking may fail to 'level the carbon playing-field'. With an internally inefficient policy such as the EU's, the first-best prescription of creating a joint market in order to harmonize emission-permit prices actually enlarges the internal domestic distortion between trading and non-trading sector, and might increase the gap in competitiveness between home's and foreign's *Y*-sector. The latter formally depends on the details of the production and utility functions, but in the plausible scenario where the gains in global efficiency are used to increase the global output of both *Y* and *X*, the assertion always holds.[18] This can be seen by recalling that before linking the marginal product G_R^i in the *Y*-sector is higher at home than in the foreign country, implying that a uniform global increase in p_y would already widen the emission-tax gap (which is given by the difference in the *value* of the marginal products: $p_y\, G_R^h - p_y\, G_R^f$). If, in addition, foreign's *Y*-sector expands, thereby further decreasing its marginal product G_R^f, the gap becomes even larger.

5. Extension: The Case of Non-Traded Goods

The above discussed model with two main countries and traded goods is oriented on the standard approach in trade economics and allows developing an intuition about the potential effects and forces at work. Admittedly, the stylized character of these models–indispensable for an analytical treatment–is often at odds with the idiosyncrasies of reality. In this section, we explore a formal modification of the model aiming to acknowledge the empirical fact that a large share of emissions arises in the production and consumption of goods–such as electricity–that are not heavily traded, at least not between far distant regions such as Europe and China. Specifically, we are referring to the transport and building (i.e. heating) sectors, and in particular to the energy sector (mainly electricity), which in total make up about 65% of all CO_2 emissions in the EU (EEA 2009). Prominent sectors that are emission intensive and characterized by heavy trade include, e.g., the cement, steel, and aluminum industries.

In view of a potential linking proposal involving such 'domestic' sectors, the question arises in how far the previously derived results still hold. E.g. the EU could link its ETS to China's electricity sector, or the transport sector, as suggested by Schneider and Cames (2009). To explore such a scenario, we modify the general model by assuming that the sector *Y* is a purely domestic industry in both countries. As a consequence, the price for good *Y* will in general be different across countries, and trade between *h* and *f* will not occur in the absence of linking. In formal terms, a competitive equilibrium in this model

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[18] The efficiency gains from linking allow re-producing the global pre-linking output without having to use all resources. Unless *X* and *Y* are close substitutes, the extra *R* will be used to obtain more units of both.

is now described by the following equations for the prices p_x and p_y^i: (i) profit maximization, i.e.

$$(17) \qquad p_x\, F_R^i(R_X^i) = p_y^i\, G_R^i(R_Y^i) = 1 \quad ,$$

(ii) consumers maximize utility, i.e. their demand is determined by $\eta^i := \eta\left(p_x / p_y^i\right)$, (iii) each country's income I^i is given by its GDP, i.e. $I^i = p_x\, X^i + p_y^i\, Y^i - R^i$, (iv) markets for all goods clear, i.e.

$$(18) \qquad \eta^h I^h + \eta^f I^f + R = \left(X^h + X^f\right) p_x \quad ,$$

$$(19) \qquad \tilde{\eta}^i I^i = Y^i p_y^i \quad ,$$

for good X and good Y, respectively, and

$$(20) \qquad S\left(p_x\right) = R^h(p_x) + R^f(p_x)$$

with $S'<0$ for the resource market. Note how the resource supply function in Eq.(20) has simplified, since it is now an argument only of the relative price p_x of good X. In fact, because goods of type Y are not internationally traded, their prices p_y^i play a role only for internal accounting, and do not matter at the international level. On the other hand, the share η^i of income spent on good X can now be different across regions, since it depends on the ratio of the international price p_x and the country-specific price p_y^i of the domestic good.

To analyze the impacts of linking, it is assumed that an 'emission market' for trade in R is established between the EU ETS and one of China's sectors, either the one integrated in international trade or the domestic sector.

Proposition 6: *Let the home country be fully capped at* $\overline{R}^h$*, with an ETS in sector X having* $\overline{R}_x^h$ *permits, and an adaptable emission tax in sector Y that ensures a constant intake of* $\overline{R}_y^h$*. If the foreign country adopts a sectoral BAU target* $\overline{R}_x^f$ *for its X-sector and an emission trading link with home's X-sector ('linking') is established, then*

- *(i) the price p_x of good X falls,*
- *(ii) resource intake (=emissions) in foreign's Y-sector increases, i.e. leakage occurs across sectors.*

If instead foreign's Y-sector is capped at the BAU level and linked to home's X-sector,

- *(iii) global resource intake remains constant, i.e. leakage does not occur.*

Proof: See Appendix A.6

The intuition essentially remains the same as in the model where both goods are traded internationally: Linking the *X*-sectors has the direct gains-from-trade effect of increasing the amount of available *X*-goods in the foreign country. This changes the marginal rate of substitution of its consumers, which then prefer to renounce at some *X*-goods in order to increase their consumption of *Y*-goods. As a consequence, the country responds by expanding production in its *Y*-sector and paying for the additional resource intake–i.e. leakage–with some of its *X*-goods obtained from emission trading. The leakage effect will, however, be relatively weaker than in the case where both goods are traded, since the foreign country expands its *Y*-sector only to supply its own consumers, and not also those of the other country.

In case of an asymmetric link from home's *X* to foreign's *Y*-sector, the foreign country receives additional *X*-goods as 'compensation' for the amount δR that is re-allocated from foreign's domestic *Y*-sector to home's *X*-sector. Foreign's only degree of freedom is to adjust its *X*-sector, since the *Y*-sector is held fixed as part of the linking agreement. However, the first-order condition 'resource price equals value of marginal product' for efficient production in the *X*-sector remains unaltered by the linking-induced trade in *R*. In fact, positive leakage would necessarily require a rise of p_x, in contradiction to the supply side relation Eq.(20), which necessarily requires p_x to fall in order for global resource supply to grow. Hence, the foreign country becomes 'stuck' in a corner solution (consumers would like to exchange some *X* for some *Y*-goods but cannot do so), which in this case prevents the occurrence of leakage.

Overall, the introduction of a domestic good has led to a certain weakening of our results, but qualitatively they remain valid. This effect is in line with intuition, in as much as all of our results are driven by trade effects, which can be expected to become weaker when one good is by definition excluded from trade, as in this section. Nevertheless, it was shown that our principal results are robust against this modification of the model framework.

6. Conclusions

This paper has analyzed the impacts of linking emission trading systems on carbon leakage, welfare, and competitiveness within a tractable Ricardo-Viner general equilibrium model with international trade in goods and resources. The considered scenarios were designed to mimic the strategic options for future permit-market linkages between some of the major players in international climate policy, namely Europe, United States, and China.

By analytically comparing pre-linking and post-linking market equilibria, we have shown that a link involving an economy without national emissions cap can provoke leakage in form of an expansion of the non-capped sector. However, the occurrence of leakage actually depends on which industries are linked to form the joint permit market: in case of asymmetric linking, i.e. when the respective output goods are imperfect substitutes, leakage is prevented and may even become negative. These results were shown to prevail qualitatively even in the presence of a non-tradable good.

Hence, from the point of view of environmental integrity, a link of the EU ETS to a sectoral trading system in China (or elsewhere) that covers similar sectors bears some negative implications. Linking across asymmetric sectors (e.g. transport, heating, and in fact any sector producing non-tradable goods) tends to reduce global emissions and thus appears favorable from the EU perspective.

One approach for regulating economy-wide emissions in developing countries is the intensity target, which was recently adopted on a voluntary basis by China. However, our analysis has shown that such a target cannot work as a substitute for an absolute cap, i.e. it does not prevent the occurrence of leakage when one of China's sectors is linked to the EU ETS, and–in terms of policy implications–should therefore not be viewed as an instrument to facilitate participation in emissions trading.

If the EU ETS establishes a link with a hypothetical US system, leakage will not occur since both regions have an economy-wide cap. The main motivation for pursuing this policy option would be to address concerns about competitiveness, i.e. the idea of harmonizing permit prices in order to 'level the carbon playing-field'. However, our results indicate that due to the EU ETS' internal segmentation this can only be partially achieved, as linking can create and increase distortions both between the EU's two sectors as well as between the EU's non-trading sector and its US counterpart.

The modeling analysis of Böhringer et al. (2009) of the EU 2020 climate policy package suggests that non-ETS sectors face higher marginal abatement costs than the EU ETS sectors. Linking the EU ETS to a US system could intensify such concerns. An obvious remedy is to include all EU sectors in the EU ETS. Alternatively, the segmented caps can be adjusted to harmonize marginal abatement costs across sectors. In the context of our model this implies tightening the EU ETS cap after linking to a US system (e.g. in form of a buy-back of permits by the EU regulator), a step that may require *ex ante* policy coordination if e.g. the resulting increase of the US allowance price raises political concerns.

Finally, the analysis allowed for an explicit representation of the ambiguous welfare effect of linking in a general-equilibrium setting. Each country's welfare change can be decomposed into an always positive gains-from-trade effect, and a terms-of-trade effect, where the sign of the latter depends on the country's trade specialization, i.e. its export and import position. In case the terms-of-trade effect turns out to be negative, the welfare impact of linking on the individual country becomes ambiguous.

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Appendix

A.1 – Proof of Proposition 1

Emission trading–in our model in the equivalent form of resource trading–will take place since the home country's binding resource constraint implies that the value of its marginal resource product is higher than in the foreign country. In the post-linking equilibrium, the marginal products F_R^i become equalized and world production of *X* efficient, leading to a larger world supply of good *X*. The size of this increase, denoted with a superscript *w* for 'world' by δX^w, only depends on the properties of the production functions, which is also true for the amount of traded resource, denoted by δR (δ denoting some finite change, as opposed to infinitesimal changes indicated by *d*). In the following, we can therefore treat both quantities as given–yet undetermined–positive constants.

By taking the ratio of the global clearing conditions for the *Y*- and *X*-markets given in Eq.(7), we obtain for the post-linking equilibrium

$$\text{(A1)} \qquad \frac{\tilde{\eta}\, p_{x/y}}{\eta} = \frac{\overline{Y}^h + Y^f}{\overline{X}^w} \quad ,$$

where a bar indicates a constrained, fixed variable. Since sector *X* is fixed after linking, i.e. it does not respond to price movements (assuming, as we do, that the constraint remains still binding after linking), the post-linking equilibrium can be characterized by investigating the comparative statics of the last equation, and of the supply side relation implied by Eq.(8)

$$\text{(A2)} \qquad S\left[\phi(p_x, p_y)\right] = \overline{R}_X^w + \overline{R}_Y^h + R_Y^f[p_y]$$

with respect to an exogenously given small increase dX^w –the effect of linking–in the world supply of *X*. The left hand side of Eq.(A1) is a function only of the prices p_x and p_y, while the world supply Y^w depends only on p_y, and hence one obtains for the total differential

$$\text{(A3)} \qquad \sigma\left(\frac{dp_x}{p_x} - \frac{dp_y}{p_y}\right) = \frac{1}{Y^w}\frac{\partial Y^f}{\partial p_y}dp_y - \frac{dX^w}{X^w} \quad ,$$

where $\sigma>0$ denotes the elasticity of substitution of the underlying utility function. Likewise, written in differential terms Eq.(A2) becomes

$$\text{(A4)} \qquad S'\phi_x dp_x = \left(\frac{\partial R_Y^f}{\partial p_y} - S'\phi_y\right)dp_y \quad \Rightarrow \quad \frac{dp_x}{p_x} = \frac{\left(p_y\left(\partial R_Y^f/\partial p_y\right) - \phi S'\tilde{\eta}\right)}{\phi S'\eta}\frac{dp_y}{p_y}$$

where we used the relationship

(A5) $$\frac{p_x\,\phi_x}{\phi}=\eta \qquad \text{with} \quad \phi_x := \frac{\partial \phi}{\partial p_x}$$

derived from Roy's identity. In view of $S'<0$ and the positive dependence of the foreign Y-sector's resource intake on the price p_y, the first term on the right-hand-side must be negative. This implies that dp_y and dp_x have always opposite signs. Substituting Eq.(A4) into Eq.(A3) yields

(A6) $$\frac{dX^w}{X^w}=\left(\frac{p_y}{Y^w}\frac{\partial Y^f}{\partial p_y}+\frac{\sigma}{\eta}\left(1-\frac{p_y\left(\partial R_Y^f/\partial p_y\right)}{\phi\,S'}\right)\right)\frac{dp_y}{p_y} \quad ,$$

which demonstrates that linking ($dX^w>0$) always leads to a positive dp_y and negative dp_x, given that the term in parenthesis is unambiguously positive. Moreover, since the resource intake in foreign's Y sector depends positively on p_y, $dp_y>0$ is a sufficient condition for leakage to occur and–by Eq.(12)–for the need to increase the resource tax τ_y^h in order to keep the resource intake in home's Y sector constant. Finally, in order for Eq.(5) to be consistent with an increased global supply, the real price of the resource must rise. □

A.2 – Proof of Proposition 2

The impact of linking on each country consists of a direct gains-from-trade effect (i.e. an increased availability of X), and the effect from the fall of p_x and the rise of p_y.

Note that the permit price, say p_E, does not need to be taken into account explicitly, since it is determined by the value of the marginal product in the X-sector, and hence proportional to p_x:

(A7) $$p_E = p_x\,F_R^h(R_x^h+\delta R)=p_x\,F_R^f(R_x^f-\delta R) \quad ,$$

where δR can be interpreted as the number of permits that are traded due to linking. For home, the partial income effect associated with the gains-from-trade generated by emission trading can thus be expressed as

(A8) $$\begin{aligned}\Delta I^h &= \left(p_x\,F^h(\overline{R}_x^h+\delta R)-p_E\,\delta R\right)-p_x\,F^h(\overline{R}_x^h)\\ &= p_x\left(F^h(\overline{R}_x^h+\delta R)-\delta R\,F_R^h(\overline{R}_x^h+\delta R)-F^h(\overline{R}_x^h)\right)=:p_x\left(X^h+\delta X_T^h\right)\end{aligned}$$

i.e. as a fixed increase of available X-goods denoted by δX_T^h, the size of which only depends on the properties of the production functions F^i. For the foreign country we get δX_T^f, in complete analogy. With welfare as function of real income as defined in Eq.(4), the marginal change in welfare for both countries can be computed by evaluating the net effect of an exogenous increase in *X*:

$$\text{(A9)} \qquad \frac{dW^i}{dX^w} = \frac{dW^i}{d(I^i/\phi)} \frac{d(I^i/\phi)}{dX^W} = U' \cdot \left(\frac{1}{\phi} \frac{\partial I^i}{\partial X^i} \frac{\partial X^i}{\partial X^w} + \frac{\partial (I^i/\phi)}{\partial p_x} \frac{\partial p_x}{\partial X^w} + \frac{\partial (I^i/\phi)}{\partial p_y} \frac{\partial p_y}{\partial X^w} \right).$$

Applying the envelope theorem and Eq.(A5) to evaluate the terms-of-trade effect, we obtain the following expression, valid for both countries:

$$\text{(A10)} \qquad \phi\, dW^i = U' \cdot \left(p_x\, dX_T^i + \left(X^i - C_x^i \right) dp_x + \left(Y^i - C_y^i \right) dp_y \right) \quad ,$$

where the differentials on the right-hand-side still depend on dX^w. The two terms in parenthesis represent the net exports of good *X* and *Y*, respectively. Hence, if home is a net exporter of good *X* or a net importer of good *Y* (or both), then the linking-induced fall of p_x and rise of p_y can lead to an overall loss of welfare.

Finally, by summing up the terms-of-trade contributions for home and foreign one finds

$$\text{(A11)} \qquad \left(X^h - C_x^h + X^f - C_x^f \right) dp_x + \left(Y^h - C_y^h + Y^f - C_y^f \right) dp_y = C_x^s\, dp_x + C_y^s\, dp_y \quad ,$$

which–apart from a factor of minus one–represent the terms-of-trade effect experienced by the resource supplier country, thus illustrating how terms-of-trade effects constitute a zero-sum-game at the global level. Since the last expression can be written as $I^s \left(\eta\, \hat{p}_x + \tilde{\eta}\, \hat{p}_y \right)$ which–by invoking the supply side relation Eq.(5) and Eq.(A5)–results to be negative if global resource supply increases, i.e. $dS > 0 \quad \Rightarrow \quad \eta\, \hat{p}_x + \tilde{\eta}\, \hat{p}_y < 0$, we can conclude that the supplier country's welfare always increases due to the positive terms-of-trade effect. □

A.3 – Proof of Proposition 3

In this case, home imports resources *R* from foreign until the price-weighted marginal products becomes equalized, i.e.

$$\text{(A12)} \qquad p_x\, F_R^h (\overline{R}_X^h + \delta R) = p_y\, G_R^f (R_Y^f - \delta R)$$

Thus, the amount of traded permits δR now depends not only on the functions F^i, but also on the price ratio $p_{x/y}$. However, assuming that emission trading from foreign to home actually takes place, the resulting effect will in all cases be some increase in *X*-output at home and a corresponding fall in *Y*-output abroad. Thus, let us assume the world supply of *X* rises by dX^h, and that of *Y* falls by dY^f. Consider again Eq.(A1) written in differential form as in Eq.(A3), now modified for the case of *X*-*Y* linking:

(A13) $$\sigma\left(\frac{dp_x}{p_x}-\frac{dp_y}{p_y}\right)=\frac{dY^f}{Y^w}-\frac{dX^h}{X^w}-\frac{1}{X^w}\frac{\partial X^f}{\partial p_x}dp_x \quad ,$$

which can be rearranged to

(A14) $$\left(\sigma+\frac{p_x}{X^w}\frac{\partial X^f}{\partial p_x}\right)\frac{dp_x}{p_x}=\frac{dY^f}{Y^w}-\frac{dX^h}{X^w}+\sigma\frac{dp_y}{p_y} \quad ,$$

where the term in parenthesis is always positive, and–by assumption–we also have $dX^h > 0$ and $dY^f < 0$. It follows that if p_y falls, then also p_x must fall. Next, consider the clearing condition for the resource market, and its total differential, in analogy with Eq.(A4):

(A15) $$S[\phi(p_x,p_y)]=\overline{R_X^h+R_Y^f}+\bar{R}_Y^h+R_X^f[p_x] \quad \Rightarrow \quad \left(\eta-\frac{p_x}{S'\phi}\frac{\partial R_X^f}{\partial p_x}\right)\frac{dp_x}{p_x}=-\tilde{\eta}\frac{dp_y}{p_y}$$

Because the last parenthesis is always positive, it follows that dp_y and dp_x must have opposite signs. But then p_y cannot fall, since this would also require p_x to fall, by Eq.(A14). Therefore p_y must rise, which, by Eq.(A15), means that p_x falls. Finally, since the resource intake of foreign's *X* sector only depends on p_x, and p_x falls, the resource intake and output of this sector must fall, i.e. negative sectorial leakage occurs. In contrast to the case of *X*-*X* linking, the relative rise of p_y is in this case less pronounced, i.e. it does not overcompensate the fall of p_x, and thus leads to a net increase of the cost ϕ for one unit of utility (i.e. $\eta\,\hat{p}_x+\tilde{\eta}\,\hat{p}_y>0$) and–consistent with negative leakage–a drop of the (real) price of *R*. □

A.4 – Proof of Proposition 4

In principle, this proof follows the same line of argumentation as the one for Proposition 1. Again, the amount of resource traded between foreign's and home's *X*-sector in the course of linking is fully determined by the condition of marginal product equalization, i.e. it is only a function of $\bar{R}_X^h, \bar{R}_X^f$, and the production technologies, as in Eq.(A8). Also as before, the global efficiency gains in the production of good *X* imply a fall of p_x and a simultaneous rise of p_y.

A rising price for *Y* constitutes an incentive for firms in the foreign country to increase their production of this good and thus use more resources, such that leakage would occur. However, for a scenario in which foreign has adopted an intensity target, the supply side relation Eq.(A2) has to be rewritten as

(A16) $$S[\phi(p_x,p_y)]=\bar{R}_X^w+\bar{R}_Y^h+\min\left\{R_Y^f[p_y],\bar{\gamma}\cdot I^f-\bar{R}_X^f\right\} \quad ,$$

implying that in the present case a higher resource intake is only consistent with the intensity target if foreign's income has become higher in the course of linking. In fact, the emission-of-GDP intensity target may even become non-binding, if the increase of foreign's income is sufficiently high. In this case, however, the scenario with intensity target would simply reduce to case 1, i.e. Proposition 1 holds. On the other side, if linking has an adverse effect on foreign's GDP, the intensity target tightens the constraint on emissions and leads to negative leakage.

Specifically, let us consider gross domestic product (as defined by the expenditure method), which is given by the value of consumption plus exports minus imports:

$$\text{(A17)} \qquad I^f = p_x X^f + p_y Y^f - \overline{R}_X^f - R_Y^f \quad .$$

Hence, in presence of a binding emission-per-GDP target $\bar{\gamma}$, resource use in foreign's *Y*-sector can be expressed as:

$$\text{(A18)} \qquad R_Y^f = \bar{\gamma}\left(p_x X^f + p_y Y^f - \overline{R}_X^f - R_Y^f\right) \quad ,$$

which in differential terms implies (denoting the income from the gains-of-trade in emissions trading by dX_T^f)

$$\text{(A19)} \qquad dR_Y^f = \frac{\bar{\gamma}}{1+\bar{\gamma}}\left(p_x dX_T^f + X^f dp_x + Y^f dp_y + p_y\, G_R^f\, dR_Y^f\right)$$

and, by rearranging,

$$\text{(A20)} \qquad \left(1 - \frac{\bar{\gamma}}{1+\bar{\gamma}} p_y\, G_R^f\right) dR_Y^f = \frac{\bar{\gamma}}{1+\bar{\gamma}}\left(p_x dX_T^f + X^f dp_x + Y^f dp_Y\right) \quad .$$

The term $\bar{\gamma}\, p_y\, G_R^f$ represents the marginal increase in foreign's emission allowances 'generated' by the intensity target if sector *Y* increases its resource input by one marginal unit. Clearly, with a binding intensity target a *ceteris paribus* expansion of the *Y*-sector (and thus GDP) must lead to fewer new allowances than would be needed to fully cover the additional resource consumption. Therefore we can conclude that $\bar{\gamma}\, p_y\, G_R^f$ must be smaller than one and, accordingly, that the parenthesis on the left hand side of Eq.(A20) is always positive. The parenthesis on the right hand side represents the partial (i.e. when holding the production of *Y* constant) income effect arising from linking in form of gains-from-trade and price changes. Thus, foreign's production of *Y* increases (decreases) and positive (negative) emission leakage occurs, if the income effect induced by linking is positive (negative). □

A.5 – Proof of Proposition 5

Since foreign has by assumption the lower permit price, the initial effect of linking is that home buys ‘permits’ and imports resources into its *X*-sector. If the barred variables denote pre-linking allocations, then the post-linking equilibrium is characterized by a common implied resource tax τ in all but home’s *Y*-sector:

$$\text{(A21)} \quad 1+\tau = p_x\, F_R^h(\overline{R}_X^h + \delta R_X^h) = p_x\, F_R^f(\overline{R}_X^f + \delta R_X^f) = p_y\, G_R^f(\overline{R}_Y^f + \delta R_Y^f)$$

subject to $\delta R_X^h + \delta R_X^f + \delta R_Y^f = 0$, as the trading system is neutral with respect to total resource use. Because foreign has an economy-wide ETS, the last part of Eq.(A21) is valid at all times, also during the linking process, and can thus be used for comparative statics. In differential terms it becomes:

$$\text{(A22)} \quad \frac{p_x}{p_y} = \frac{G_R^f(R_Y^f)}{F_R^f(R_X^f)} \quad \Rightarrow \quad \frac{dp_x}{p_x} - \frac{dp_y}{p_y} = \frac{G_{RR}^f}{G_R^f}\, dR_y^f - \frac{F_{RR}^f}{F_R^f}\, dR_x^f \quad .$$

At the same time, the differential of the global supply-demand constraint Eq.(A1), in analogy with Eq.(A3), is given by

$$\text{(A23)} \quad \sigma\left(\frac{dp_x}{p_x} - \frac{dp_y}{p_y}\right) = \frac{dY^f}{Y^w} - \frac{dX^w}{X^w} = \frac{G_R^f}{Y^w}\, dR_y^f - \frac{F_R^f}{X^w}\, dR_x^f - \frac{F_R^h}{X^w}\, dR_x^h \quad .$$

Substituting Eq.(A22) into Eq.(A23) leads to the following expression:

$$\text{(A24)} \quad \left(\sigma \frac{G_{RR}^f}{G_R^f} - \frac{G_R^f}{Y^w}\right) dR_y^f = \left(\sigma \frac{F_{RR}^f}{F_R^f} - \frac{F_R^f}{X^w}\right) dR_x^f - \frac{F_R^h}{X^w}\, dR_x^h \quad .$$

The factors in parenthesis are clearly negative. Hence, given our assumption that home will be a net importer of resource permits, i.e. $dR_x^h > 0$, the term dR_x^f cannot be positive, since this would imply also a positive dR_y^f, which in turn would mean foreign is a net importer of permits. Therefore, linking must lead to a reduction of foreign’s production of good *X*. Although for foreign’s *Y*-sector the change in output remains ambiguous, the change in the price ratio $p_{x/y}$ is uniquely determined: if $dR_y^f > 0$, then the right-hand-side of Eq.(A24) becomes negative, and hence $d(p_{x/y}) < 0$. If, on the other hand, $dR_y^f < 0$, then $dY^w < 0$ and $dX^w > 0$ follow, which means that the middle-part of Eq.(A23) becomes negative, and again $d(p_{x/y}) < 0$ must hold. Moreover, since total global resource supply must remain constant under the considered cap-and-trade system, the cost of utility function ϕ, which actually represents the inverse of the real price of one unit of the resource, must also stay constant, which by Eq.(5) and Eq.(A5) requires $\eta\, \hat{p}_x + \tilde{\eta}\, \hat{p}_y = 0$, i.e. the change in p_y and p_x must be of opposite signs. Therefore we can conclude that p_x falls and p_y increases, which proves assertion (i) and (ii).

Given the rise in p_y, it also becomes evident that the tax τ_y^h in home's Y-sector must be increased in order to keep this sector's total resource intake constant, as the latter is governed by $1+\tau_y^h = p_y\, G_R^h(\overline{R}_y^h)$. On the other hand, if home's X-sector is to expand, despite the falling price of p_x, then the corresponding resource tax (or emission permit price) must have decreased due to linking, thus completing the proof of assertion (iii).

It remains to show that it is possible and plausible for the gap between the emissions prices in home's and foreign's Y-sector to increase. In formal terms, this requires

$$\text{(A25)} \quad d\tau_y^h = G_R^h(\overline{R}_y^h)\, dp_y \; > \; d\tau^f = G_R^f(\overline{R}_y^f)\, dp_y + p_y\, G_{RR}^f(\overline{R}_y^f)\, dR_y^f$$

to be true. Given that we have $G_R^h > G_R^f$ by assumption, the inequality holds whenever dR_y^f is positive, or negative but sufficiently close to zero, i.e. whenever linking leads to an expansion or only small contraction of foreign's Y-sector. Conversely, a closing of the emissions-price gap can only occur if foreign's Y-sector contracts sufficiently. This would correspond to a case in which resources from both foreign sectors are reallocated to home's X-sector. Although theoretically possible, such a scenario is not very plausible, as it would mean that all efficiency gains realized in the global production of good X are used to produce more only of good X, and that the global production of Y actually decreases. Eq.(A24) implies that this could happen if X and Y are very close substitutes, since for $\sigma \to \infty$ one infers that the sign of both dR_x^f and dR_y^f must be negative. Conversely, if X and Y are perfect complements, i.e. $\sigma \to 0$, Eq.(A23) requires that both dX^w and dY^w must be positive, and thus $dR_y^f > 0$. □

A.6 – Proof of Proposition 6

Consider first a symmetric X-X link. As before, we assume that the foreign country sells some amount δR of resource to the home country, receiving an amount of δX in return which exceeds the loss of domestic X production and which is defined solely by the condition of marginal product equalization, and hence does not depend on any prices. Prior to linking, the foreign country's firms and consumers–taking the price p_x as given–implicitly maximize

$$\text{(A26)} \quad \max_{R_x^f, R_y^f} U^f\left[F^f(R_x^f) - \frac{\left(R_x^f + R_y^f\right)}{p_x}, G^f(R_y^f) \right] \; .$$

Regarding the optimal choice for sector Y, a homothetic utility implies

$$(\text{A27})\qquad \frac{\partial_x U^f}{\partial_y U^f} =: MRS\left(\frac{C_y^f}{C_x^f}\right) = p_x\, G_R^f \qquad ,$$

where *MRS* denotes the marginal rate of substitution. After linking to the home country's *X*-sector, the maximization problem in Eq.(A26) is simplified to one of a single variable, namely R_y^f , because foreign's *X*-sector is now fully determined by the condition of marginal product equalization. Foreign's general equilibrium reaction to a positive 'shock' δX can thus be evaluated by considering the comparative statics of Eq.(A27), written as

$$(\text{A28})\qquad MRS\left(\frac{G^f(R_y^f)}{\overline{X}^f + \delta X - \left(\overline{R}_x^f + R_y^f\right)/p_x}\right) = p_x\, G_R^f \quad ,$$

where the pre-linking equilibrium defines the parameters $\overline{X}^f$ and $\overline{R}_x^f$. Computing all derivatives yields

$$(\text{A29})\ \left(\frac{\partial\left(C_y^f / C_x^f\right)}{\partial X^f} dX^f + \frac{\partial\left(C_y^f / C_x^f\right)}{\partial R_y^f} dR_y^f + \frac{\partial\left(C_y^f / C_x^f\right)}{\partial p_x} dp_x\right) MRS' = G_R^f\, dp_x + p_x\, G_{RR}^f\, dR_y^f \ .$$

Noting that the derivative *MRS'* is positive and since, evidently, we have

$$(\text{A30})\qquad \frac{\partial\left(C_y^f / C_x^f\right)}{\partial X^f} < 0 \qquad \frac{\partial\left(C_y^f / C_x^f\right)}{\partial R_y^f} > 0 \qquad \frac{\partial\left(C_y^f / C_x^f\right)}{\partial p_x} < 0$$

the equation can be written in a qualitative way ('neg' denoting negative terms, 'pos' positive ones) as

$$(\text{A31})\ \left(G_R^f - [...neg...]\cdot MRS'\right) dp_x + \left(p_x\, G_{RR}^f - [...pos...]\cdot MRS'\right) dR_y^f = [...neg...]\cdot MRS'\, dX^f$$

The still needed relation linking dp_x and dR_y^f can be obtained from the resource supply relation Eq.(21). With a binding constraint, the resource intake for all sectors except foreign's *Y*-sector remains constant, and thus any change in the global supply must be due to a change in R_y^f :

$$(\text{A32})\qquad dS = dR_y^f = S'\, dp_x \quad .$$

Substitution into Eq.(A31) yields

$$(\text{A33})\qquad dp_x = \frac{[...neg...]\cdot MRS'}{\left(G_R^f - [...neg...]\cdot MRS' + p_x\, S' G_{RR}^f - [...pos...]\cdot S'\, MRS'\right)} dX^f \quad ,$$

which–given the unambiguous negative sign of the coefficient–demonstrates that linking leads to a fall in the price p_x. By virtue of Eq.(A32), it follows that foreign's *Y*-sector expands, i.e. leakage occurs. Finally, the efficiency condition $p_y^f \, G'(R_y^f) = 1$ also implies that the price p_y^f increases.

In case of an asymmetric link from home's *X* to foreign's *Y*-sector, the foreign country receives additional goods *X* as 'payment' for the amount δR of resource that is traded from its domestic *Y*-sector to home's *X*-sector. Foreign's only degree of freedom is to adjust its *X*-sector, since the *Y*-sector has become 'fixed' as part of the linking agreement. However, the first-order condition for efficient production in the *X*-sector remains unaltered by the linking-induced trade in *R*, since foreign's maximization problem after linking

$$\text{(A34)} \qquad \max_{R_x^f} U^f \left[F^f(R_x^f) + \delta X - \frac{\left(R_x^f + \overline{R}_y^f\right)}{p_x}, G^f(\overline{R}_y^f - \delta R) \right]$$

only implies the equalization of resource price and value of marginal product:

$$\text{(A35)} \qquad p_x \, F_R^f(R_x^f) = 1 \quad .$$

Therefore, foreign's *X*-sector expands only if p_x increases. But since the supply relation Eq.(A32) allows an increase in global resource supply only for a decrease in p_x, this cannot happen, allowing to conclude that global resource use must remain unaltered. □

References

Alexeeva-Talebi, A., N. Anger (2007): Developing Supra-European Emissions Trading Schemes: An Efficiency and International Trade Analysis. ZEW Discussion Paper No. 07-038.

Alexeeva-Talebi, A., N. Anger, A. Löschel (2008): Alleviating Adverse Implications of EU Climate Policy on Competitiveness: The Case for Border Tax Adjustments or the Clean Development Mechanism? ZEW Discussion Paper No. 08-095.

Anger, N., (2008): Emissions trading beyond Europe: linking schemes in a post-Kyoto world. *Energy Economics* 30, 2028-2049.

Anger, N. B. Brouns, J. Onigkeit (2009): Linking the EU emission trading scheme: economic implications of allowance allocation and global carbon constraints. *Mitigation and Adaptation Strategies for Global Change* 14, 379-398

Babiker, M., Reilly, J., Viguier, L. (2004): Is international emissions trading always beneficial? *Energy Journal* 25(2), 33-56.

Bernstein, P., D.W. Montgomery, T.F. Rutherford (1999): Global impacts of the Kyoto agreement: results from the MS-MRT model. *Resource and Energy Economics* 21, 375-413.

Böhringer, C., Rosendahl, K.E. (2009): Strategic partitioning of emission allowances under the EU Emission Trading Scheme. *Resource and Energy Economics* 31 (3), 182-197.

Böhringer, C., T.F Rutherford, R.S.J Tol (2009): The EU 20/20/2020 targets: An overview of the EMF 22 assessment. *Energy Economics* 31, S268-S273.

Buchner, B., C. Carraro (2007): Regional and sub-global climate blocs: a cost-benefit analysis of bottom-up climate regimes. In: Carraro, C., C. Egenhofer (eds.): Climate and Trade Policy. Bottom-up approaches towards global agreement. Edward Elgar, Cheltenham UK.

Carbone, J.C., Helm, C., Rutherford, T.F. (2009): The case for international emission trade in the absence of cooperative climate policy. *Journal of Environmental Economics and Management* 58 (3), 266-280.

Copeland, B.R. and Taylor, M. (2005): Free trade and global warming: a trade theory view of the Kyoto protocol. *Journal of Environmental Economics and Management* 49 (2), 205-234.

Dijkstra, B.R., E. Manderson and Tae-Yeoun Lee (2008): Partial International Emission Trading, Research Paper 2008/27, University of Nottingham Research Paper Series.

EEA – European Environment Agency (2009): Annual European Community greenhouse gas inventory 1990–2007 and inventory report 2009 Submission to the UNFCCC Secretariat. Version 27 May 2009. Accessed via EEA greenhouse gas viewer.

EPA – U.S. Environmental Protection Agency (2009): EPA Analysis of the American Clean Energy and Security Act of 2009 H.R. 2454 in the 111th Congress. 6/23/09.

EU Commission (2008): Impact Assessment Commission Staff Working Document. Accompanying the Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020. Brussels, 23 Janvier 2008 SEC(2008) 85/3.

EU Commission (2009): Towards a Comprehensive Climate Change Agreement in Copenhagen: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2009) 39/9, Brussels.

European Union (2009a): Decision No406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020.

European Union (2009b): Directive 2009/29/EC of the European Parliament and of the Council of 23 April 2009 so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community.

Flachsland, C., R. Marschinski, O. Edenhofer (2009a): Global Trading versus Linking. Architectures for International Emissions Trading. *Energy Policy* 37, 1637-1647.

Flachsland, C., R. Marschinski, O. Edenhofer (2009b): To link or not to link: Benefits and disadvantages of linking cap-and-trade systems. *Climate Policy* 9, 358-372.

Helm, C. (2003): International emissions trading with endogenous allowance choices. *Journal of Public Economics* 87, 2737-2747.

Houser, T., Bradley, R., Childs, B., Heilmayr, R. (2008): Leveling the Carbon Playing Field: International Competition and US Climate Policy Design. Peterson Institute and World Resource Institute, Washington D.C.

Larsen, J., Heilmayr, R. (2009): Emission Reductions under Cap-and-trade Proposals in the 111th Congress. World Resources Institute. June 25, 2009. Available at: http://pdf.wri.org/usclimatetargets_2009-06-25.pdf

Markusen, J.R. (1983): Factor Movements and Commodity Trade as Complements. *Journal of International Economics* 14, 341-356.

Mayer, W. (1974): Short-Run and Long-Run Equilibrium for a Small Open Economy. *Journal of Political Economy* 82 (5), 955-967.

McKibbin, W.J., Shackleton, R., Wilcoxen, P.J. (1999): What to expect from an international system of tradable permits for carbon emissions. *Resource and Energy Economics* 21 (3-4), 319-346.

McKibbin, W.J., A. Morris, P.J. Wilcoxen (2008): Expecting the Unexpected: Macroeconomic Volatility and Climate Policy. Discussion Paper 08-16, Harvard Project on International Climate Agreements, Belfer Center for Science and International Affairs, Harvard Kennedy School, November.

Neary, P. (1978): Short-Run Capital Specificity and the Pure Theory of International Trade. *Economic Journal* 88, 488-510.

Paltsev, S., Reilly, J.M., Jacoby, H.D., Tay, K.H. (2007): How (and why) do climate policy costs differ among countries?, in: M.E. Schlesinger, H. Kheshgi, J.B Smith, F.C. de la Chesnaye, J.M. Reilly, T. Wilson, C. Kolstad (eds), Human- Induced Climate Change: An Interdisciplinary Assessment, Cambridge University Press, Cambridge, UK, 282-293.

Rehdanz, K., Tol, R.S.J. (2005): Unilateral regulation of bilateral trade in greenhouse gas emission permits. *Ecological Economics* 54, 397-416.

Russ, P., Ciscar, J.-C., Saveyn, B., Soria, A., Szábó, L., Van Ierland, T., Van Regemorter, D., Virdis, R., (2009): Economic Assessment of Post-2012 Global Climate Policies: Analysis of Greenhouse Gas Emission Reduction Scenarios with the POLES and GEM-E3 Models, EU Commission Joint Research Centre Report.

Schneider, L. (2007): Is the CDM fulfilling its environmental and sustainable development objectives? An evaluation of the CDM and Options for improvements, Report prepared by Öko-Institut e.V. for WWF, 5 November 2007, Available online at: http://www.oeko.de/oekodoc/622/2007-162-en.pdf

Schneider, L., M. Cames (2009): A framework for a sectoral crediting mechanism in a post-2012 climate regime. Report for the Global Wind Energy Council Berlin, 28 May 2009. Öko-Institut.

Stankeviciute L., Kitous A., Criqui P. (2008): The fundamentals of the future international emissions trading system. *Energy Policy* 36 (11), 4272-4286.

Stavins, R.N. (2009): What Hath Conpenhagen Wrought? A Preliminary Assessment of the Copenhagen Accord. Blog posted on December 20, 2009. Available at: http://belfercenter.ksg.harvard.edu/analysis/stavins/?p=464

Sterk, W., Braun, M., Haug, C., Korytarova, K., Scholten, A. (2006): Ready to Link up? Implications for Design Differences for Linking Domestic Emissions Trading Schemes: Joint Emissions Trading as a Socio-Ecological Transformation, JET-SET Project Working Paper I/06.

Stern, N. (2008): Key elements of a global deal on climate change. Available at: http://www.lse.ac.uk/collections/granthamInstitute/publications/KeyElementsOfAGlobalDeal_30Apr08.pdf

Tietenberg, T.H. (2006): Emissions Trading: Principles and Practice. 2nd edition, RFF Press, Washington D.C.

Tuerk, A., M. Mehling, C. Flachsland, W. Sterk (2009): Linking Carbon Markets. Concepts, case studies and pathways. *Climate Policy* 9, 341-357.