# Reassessing Carbon Leakage

Glen Peters[1]
Industrial Ecology Programme
Norwegian University of Science and Technology
Trondheim, Norway
glen.peters@ntnu.no

A paper for the Eleventh Annual Conference on Global Economic Analysis, "Future of Global Economy", Helsinki, Finland, June 12-14, 2008

## *Abstract*

The issue of carbon leakage – where emission reductions in Annex B countries are offset by emission increases in non-Annex B countries – is often raised as an issue that will undermine climate policy. It is argued that under tight emissions constraints, some production will relocate to regions without emission constraints. The IPCC finds little evidence of carbon leakage and if it exists, it is most likely to be offset by positive spill-over effects. This finding seemingly contradicts the rapid growth in both global $CO_2$ emissions and international trade. The underlying reason is that the IPCC only considers climate policy induced changes in emissions, while currently much of the growth in international trade and the location of production are driven by existing economic factors. In this paper, I argue for a redefinition of carbon leakage to include all emissions emitted in the production of traded products. This quantifies the separation between the environmental impacts of a countries consumption compared to production. Analysis of the emissions embodied in trade flows from 1990 to 2002 show evidence of a shift in the location of production and the products traded. There is a notable growth in China and given trends since 2002, it is likely that the separation between consumption and production has increased further. By considering the total emissions from the production of traded products, a different perspective of the role of trade in climate policy can be taken. This new focus considers trade as a tool to mitigate emissions and is a fruitful area for further research.

[1] Address as of June 2008: Center for International Climate and Environmental Research (CICERO), Oslo, Norway.

## *Introduction*

Carbon Leakage – where emission reductions in Annex B countries are offset by emission increases in non-Annex B countries – has often been discussed as a process undermining the Kyoto Protocol. Most economic and statistical studies find that carbon leakage is not a significant problem in reality [1, 2]. Using these studies to conclude that carbon leakage does not need consideration in future climate policy grossly misrepresents a key driver for today's dynamic economic growth – international trade.

International trade is more dynamic than most other factors driving emissions. Economic growth was a key driver for emissions [3], but Figure 1 shows that international trade is growing far more rapidly than GDP, emissions, and population. While net trade – exports minus imports – is unlikely to be a key driver of emissions in most developing countries [4], changing trade structure does represent a relocation of production and emissions [5]. Given that only a small group of countries have quantifiable emissions reductions in the Kyoto Protocol, then rapidly changing trade volume and structure may represent a significant outsourcing of pollution. In 2001, one-quarter of global emissions were embodied in international trade flows with a significant net import into Annex B countries [5]. Figure 1 suggests this is changing rapidly. Recent research shows that emissions from the production of Chinese exports have increased from 16% of Chinese emissions in 1990 to 33% in 2005 [6]. The low carbon leakage reported by the IPCC seemingly contradicts these underlying dynamics.

Despite the small focus of carbon leakage by the IPCC, stake-holders are showing increased focus on the relationship between trade and climate policy[2]. Trade has important implications for climate policy in relation to participation, carbon leakage, competitiveness concerns, and increasingly for mitigation [5, 7]. Arguably, trade has been pivotal in transforming some countries from poor to rich and there are opportunities for trade to similarly transform the climate debate.

The aim of this paper is a critical assessment of how the IPCC defines carbon leakage and how a different paradigm provides new insights. The next section discusses the use of carbon leakage by the IPCC and follows with a "weaker" definition of carbon leakage. Time-series analysis is used to look at changes in emissions embodied in trade over time and finally the implications for climate policy are discussed.

---

[2] The increased interest in trade and climate issues is reflected in publications and reports, workshops and conferences, media, and political rhetoric. A new thread in negotiations may begin following the high-level meeting of trade ministers in conjunction with the Bali UN climate conference.

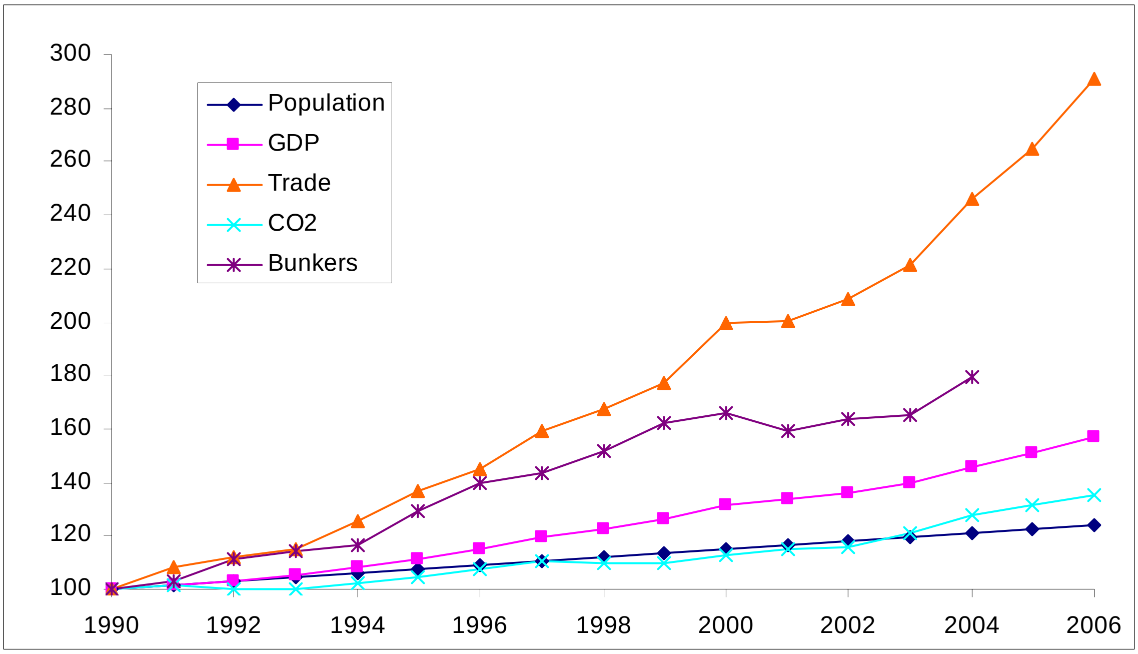


Figure 1: The growth in various macro-variables from 1990 to 2006. Population has grown the slowest with a 25% increase, there has been a steep increase in $CO_2$ emissions after 2002 (35% increase since 1990), GDP has increased almost 60%, bunker fuel consumption almost 100%, with international trade growing almost 200%. Source: Population, US Census Bureau, GDP and trade in constant prices from national accounts data.un.org, $CO_2$ from CDAIC Trends, and bunker consumption from WRI CAIT.

## *IPCC carbon leakage*

Traditionally, economists have taken a very narrow view of the term carbon leakage. The IPCC defines carbon leakage as [1, Glossary]:

> The part of emissions reductions in Annex B countries that may be offset by an increase of the emissions in the non-constrained countries above their baseline levels. This can occur through (1) relocation of energy-intensive production in non-constrained regions; (2) increased consumption of fossil fuels in these regions through decline in the international price of oil and gas triggered by lower demand for these energies; and (3) changes in incomes (thus in energy demand) because of better terms of trade. […] On most occasions, leakage is understood as counteracting the initial activity. Nevertheless, there may be situations where effects attributable to the activity outside the project area lead to GHG emission reductions. These are commonly called spill-over. While (negative) leakage leads to a discount of emission reductions as verified, positive spill-over may not in all cases be accounted for.

The definition is clearly embedded in the paradigm of computable-general equilibrium modeling and represents marginal changes due to changed climate policy. Interesting, the definition suggests that carbon-leakage is not important due to spill-over effects. Analysis of the Clean Development Mechanism suggests that technology diffusion (spill-over effects) may be limited and only occur in certain cases [8]. While effects (2), (3), and spill-over effects are important, they may be considered as secondary effects. Traditionally, the debate often surrounds effect (1) – also known as the Pollution Haven Hypothesis – which focuses on shifting production. While trade is not explicitly mentioned in the definition, it enters via effect (1) when relocation causes changes in trade.

The IPCC definition of carbon leakage is quite restrictive and it is perhaps no surprise that leakage is found to be small[3]. It is noteworthy that the definition only considers “relocation of energy-intensive industries”. The use of relocation implies that an industry must physically close down in an Annex B country and reopen in a non-Annex B country, while overall consumption is maintained. The net change in emissions would represent leakage – in this case, spill-over effects would be highly important. A focus on industrial relocation misses other important effects. Most significantly, an existing industry in a non-Annex B country may expand its production, that is, increased Annex B consumption is met by increased non-Annex B production [5]. In this later case, spill-over effects will be much less important.

The IPCC definition only includes “energy-intensive industries”. Whilst energy-intensive industries are important, they are not the dominant source of global or embodied emissions. Energy-intensive industries are more pollution intensive on a relative basis, but at the aggregated level manufactured products dominate. For instance, the growth in China’s exports is dominated by emissions of textiles, chemicals, electronics, and manufactured products [6]. Clearly, a focus on energy-intensive industries is misplaced.

Importantly, the IPCC definition refers to only a “part of” the emissions. In particular, this implies the part of the changes that are due to climate policy. Studies have shown that environmental policy is not a dominate factor in a companies relocation decisions and instead a myriad of other factors are more important [2]. To date only some studies have found evidence that relocation is due to environmental legislation [2, 9, 10].

In terms of international trade, potential carbon leakage under the IPCC definition only represents a small fraction of international trade and as the definition implies, may be offset by spill-over effects. Yet other evidence suggests that significant flows of pollution exist in traded products [5, 11-13]. The IPCC definition of carbon leakage may be too narrow to adequately analyze the relationship between trade and climate policy. To understand the relationship between trade and climate policy requires a different viewpoint.

---

[3] The restrictive nature of carbon leakage can be considered in a thought experiment. Consider a country (A) that changes climate policy. Assume that A has no policy towards climate change pre-2000, but in 2000 introduces a carbon tax. What would be the carbon leakage in 2005? To physically measure carbon leakage, one would first need to know what the emissions in all countries would be in 2005 if there was no climate policy in country A (unmeasurable). Next, one needs to compare this with the actual emissions in all other countries due to the policy in A and separate only those changes that result from the climate policy in A. Given the complex global economic system and myriad of factors causing changes, carbon leakage is not physically measurable. Thus, carbon leakage is only really useful as a modeling exercise.

## *Redefining carbon leakage*

A much weaker, but more applicable, definition of carbon leakage considers non-climate policy induced increases in emissions [14]. "Weak carbon leakage" considers the emissions from the production of goods and services exported from non-Annex B countries to Annex B countries. If $f_{rs}$ represents the total emissions[4] in country $r$ to produce products and services exported to country $s$, then the carbon leakage from non-Annex B to country $s$ is

$$L_s = \sum_{r \in \text{non-B}} f_{rs} \quad (1)$$

and the total carbon leakage from non-Annex B to Annex-B is

$$L = \sum_{s \in \text{B}} \sum_{r \in \text{non-B}} f_{rs} \quad (2)$$

Using this definition it is possible to determine the carbon leakage between countries (e.g., USA) and arbitrary regions (e.g., the European Union).

Weak carbon leakage has a much wider scope that considers all international trade, not changes specifically due to climate policy. Arguably, with limited participation in binding emission commitments, it is not important what causes the changes in trade and emissions, but rather, the fact that emissions may be growing unchecked in countries with binding commitments. As an example, the growth in the emissions embodied in exports from China is unlikely a result of Annex B climate policies, but has significant implications for global emissions. Only weak carbon leakage can capture this phenomenon.

Changes in weak carbon leakage over time are of importance as it *may* represent a growing difference between a country's emissions from production and consumption. Under a weaker definition of carbon leakage, it is not necessary for a company to close-down and relocate to a non-Annex B country. Rather, it is only necessary for expanded production to occur in non-Annex B countries.

The original rationale for the "weak" definition of carbon leakage was to critique the Environmental Kuznets Curve (EKC). The argument follows that the EKC may exist when considering the territorial emissions from a country, but may not exist when adjusted for trade. Several studies have now confirmed that it is unlikely that the EKC exists if trade-adjustments are made [5, 15-17]. If the EKC exists for production, then it may not exist for consumption.

Quantifying weak carbon leakage could be directly applicable to current post-Kyoto negotiations. Carbon leakage or emissions embodied in trade could be one way to partially place a cap on developing country emissions – the cap is placed on non-Annex B exports [7]. Tracking a county's consumption-based emissions over time may offer many advantages and insights into climate negotiations and robust policy design [5, 18, 19].

The use of trade-adjusted inventories does not imply that trade is bad for the environment. To the contrary, emissions embodied in trade are essential to reduce

[4] This includes emissions in the entire domestic supply-chain.

global emissions – as long as the correct trade flows occur. As an example, a country rich in mineral resources may remain a net exporter of pollution (eg, South Africa), while a country poor in natural resources may be a net importer of pollution (eg, Japan). The key is to produce products where both environmental and economic objectives are met [18].

## Estimates of weak carbon leakage over time

Figure 2 shows how the share of global trade has shifted since 1990. The share of trade from Annex B to Annex B has decreased from 60% of world trade in 1990 to 51% in 2002, from Annex B to non-Annex B has remained static at 16%, from non-Annex B to Annex B has increased slightly from 16% to 20%, and from non-Annex B to non-Annex B has double from 8% to 14%. In terms of emissions, the changes are different since different countries have different emission intensities. The distribution of the $CO_2$ emissions embodied in international change for Annex B to Annex B was 47% in 1990 to 28% in 2002, from Annex B to non-Annex B has remained static at 13%, from non-Annex B to Annex B has increased slightly from 25% to 28%, and from non-Annex B to non-Annex B has increased from 15% to 21%. In 1990, Annex B countries produced 60% of the global emissions from producing exports, while this has reduced to 51% in 2002. This represents a significant shift in the global production of exported products, from Annex B to non-Annex B countries.

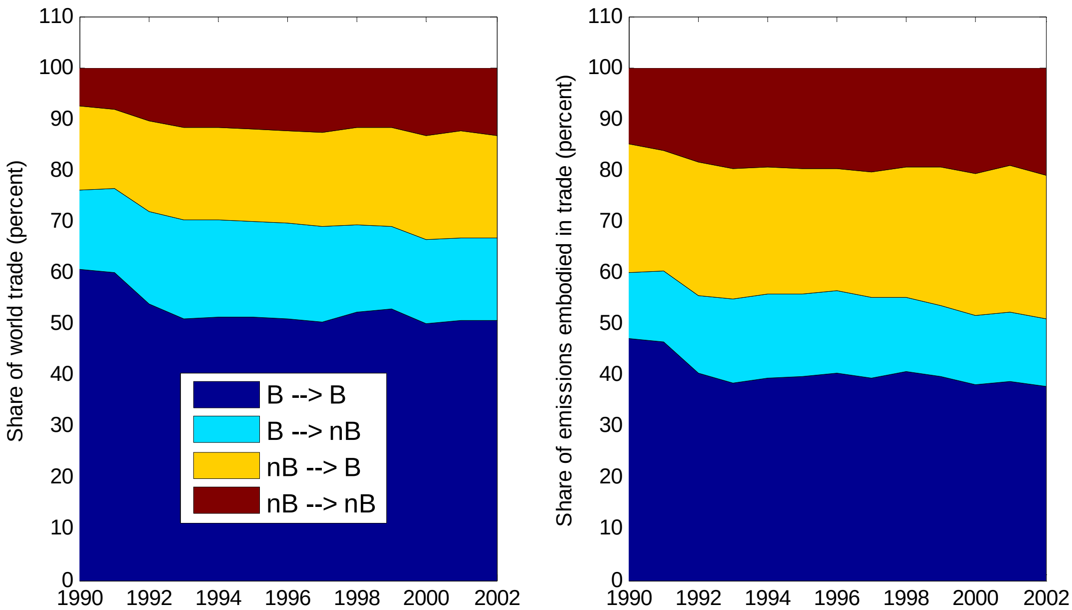


Figure 2: The left figure shows the distribution of world trade in current prices and the right figure shows the distribution in terms of $CO_2$ emissions. B is short for Annex B, while nB is short for non-Annex B.

The shifts in Figure 2 differ for monetary values and $CO_2$ emissions. This suggests there is a shift also in the products traded and the countries exporting. Figure 3 shows how the products have changed the distribution of emissions embodied in trade. The most striking changes are from non-Annex B countries to Annex B countries which represents carbon leakage. In 1990, almost half of non-Annex B to Annex B trade was due to primary products (Agriculture and Mining), but this had dropped substantially by 2002. The most significant increases are due to machinery, manufactured products, electronic equipment, textiles, and so on.

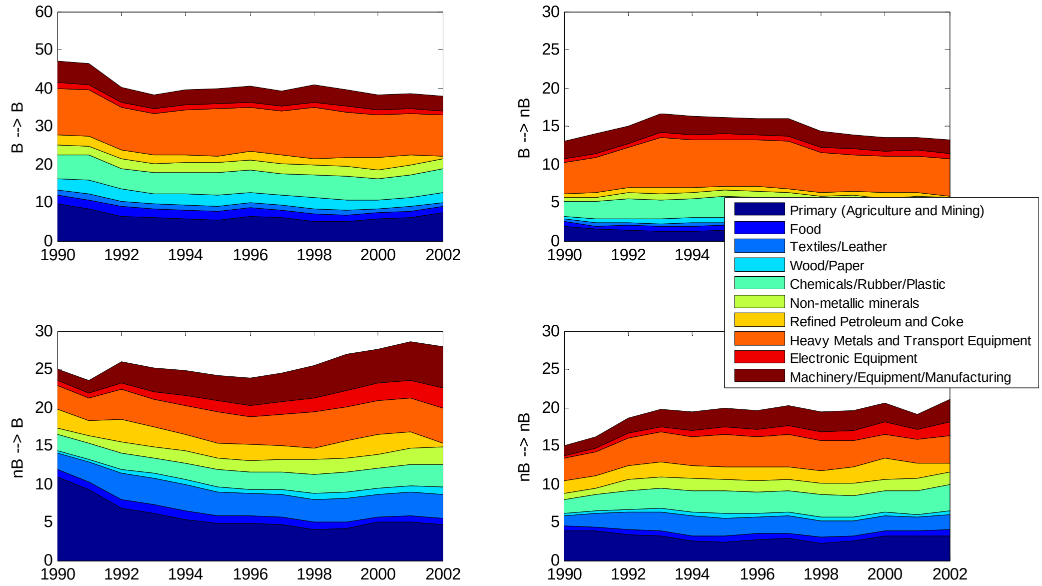


Figure 3: The distribution of products responsible for the changing distribution of emissions embodied in trade. "B → B" represents the emissions in Annex B to produce products exported to Annex B, "nB → B" represents the emissions in non-Annex B to produce products exported to Annex B (carbon leakage), and so on.

Likewise, the producing countries have changed since 1990, Figure 4. For Annex B countries, some European production has been replaced by production in Russia and the Former Soviet. While for non-Annex B countries, China has emerged as a producer, increasing its share of emissions embodied in global trade from 6% in 1990 to 18% in 2002. The majority of this growth has been exports to Annex B countries which represents a significant growth in carbon leakage from China to Annex B.

There has also been a change in the countries which receive the imports, but this is much less than the change for exports. Figure 5 shows that the largest changes are for the increase in trade to the US, particularly from non-Annex B countries (notably, China). This has been at the expense of reduced trade from Europe.

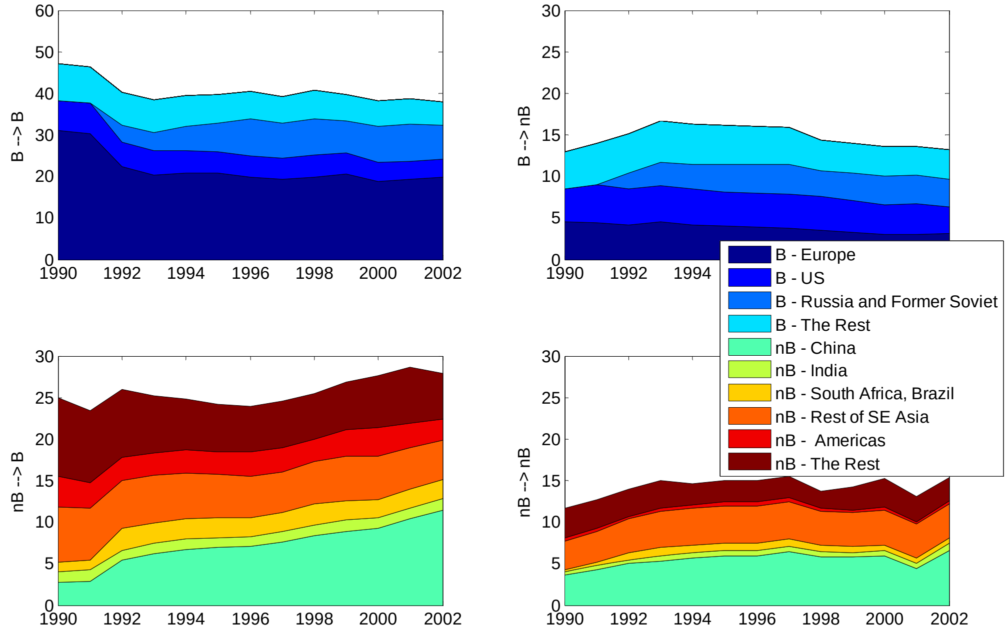


Figure 4: The country's producing exported products have changed considerably since 1990. "B → B" represents the emissions in Annex B to produce products exported to Annex B, "nB → B" represents the emissions in non-Annex B to produce products exported to Annex B (carbon leakage), and so on.

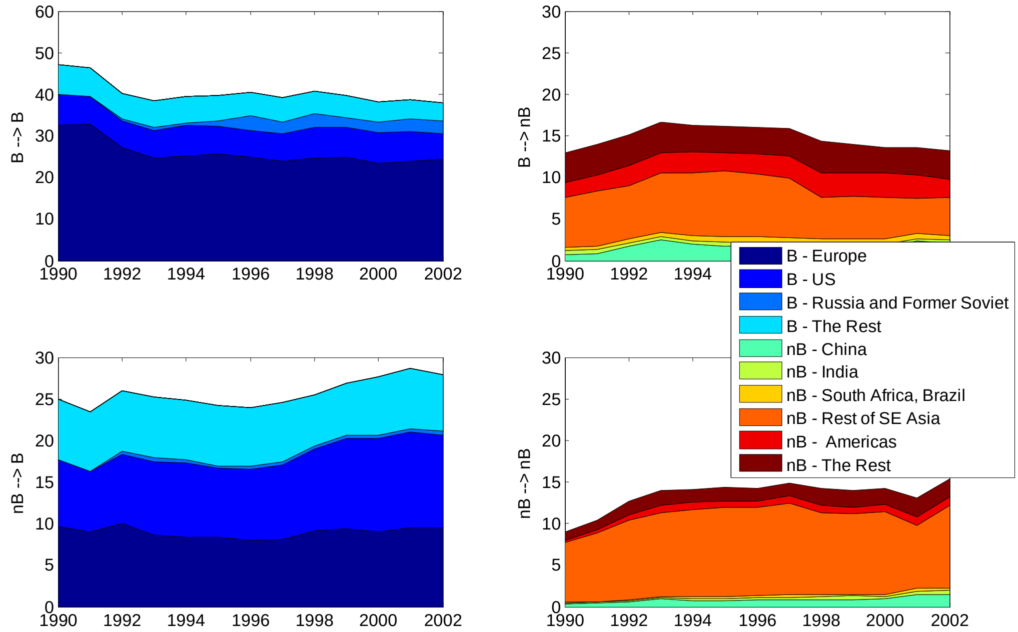


Figure 5: The country's consuming traded products have also changed since 1990, but less than for production. In this figure, the emissions are allocated to the consuming country and not the producing country. "B → B" represents the emissions in Annex B to produce products imported to Annex B, "nB → B" represents the emissions in non-Annex B to produce products imported to Annex B (carbon leakage), and so on.

## Discussion

A weaker definition of carbon leakage to consider non-climate policy induced increases in emissions is more consistent with global trends in emissions. Global $CO_2$ emissions have increased 35% from 1990 to 2006 and since joining the World Trade Organization in 2001, Chinese emissions have increased 80% (150% from 1990) and now China is the world's largest emitter of $CO_2$ [20]. Non-Annex B countries are responsible for virtually all the growth in $CO_2$ emissions as the "hot-air" in the former Soviet States, Germany, and the United Kingdom balances the emissions growth in other Annex B countries. Combined with increased international trade, the data suggests that there has been an ongoing shift of production from Annex B to non-Annex B countries. It is highly unlikely that this shift is due to climate policy in Annex B countries, but rather existing economic factors.

The fact that emissions are growing unchecked in non-Annex B countries is a reason for concern, regardless if this is caused by Annex B climate policies. Post-Kyoto policy needs to address emissions growth in non-Annex B countries and if a part of this growth is due to non-climate policy induced increases in trade then this should be addressed. As this study shows, the shifts in production up to 2002 are of concern, and given the explosion in Chinese emissions since 2002, it is likely that the effective weak carbon leakage has increased substantially. The IPCC approach to carbon leakage only seeks climate policy induced shifts in emitting countries. This places very little emphasis on the growth in China and other non-Annex B countries and the IPCC argues that spill-over effects will offset any likely increases anyway. By broadening the scope of carbon leakage, policy makers have a new means to address the growth in non-Annex B emissions.

Current interest in the nexus between trade and climate policy is growing. Discussions on industrial competitiveness, carbon leakage, and border-tax adjustments are becoming prominent in political rhetoric and the media. Yet, the IPCC has placed surprisingly little emphasis on these policy-relevant areas and instead focused on issues such as technology. Many trade-climate discussions have focused on negative issues, such as, legality of trade measures [21-24]. However, research and debates are highlighting the many fruitful synergies between climate and trade policy [5, 7, 18, 19, 25-27]. A harmonization of trade and climate policy can reduce emissions; product standards can drive down production costs and help speed the global diffusion of products; investment funds can be prioritized along key trade flows; trade-adjusted inventories can be used to partially bring developing countries into emission caps; and as a option of last resort, trade can be used for enforcement [28, 29]. Expanding the research agenda into using trade as a means of mitigation is overdue.

## *Annex B: Methodology*

The numbers in this report are based on the analysis of emissions embodied in trade [5] applied to the trade time-series in GTAP. The total (direct and indirect) emission intensity is applied to trade-flows.

$$f_{rs}(t) = \left(F_r (I - A_{rr})^{-1}\right) y_{rs}(t) = F^t{}_r y_{rs}(t) \quad (3)$$

where $F_r$ is the direct emissions intensity in each industry sector in region $r$ (a row vector), $I$ is the identity matrix, $A_{rr}$ is the domestic requirements for domestic production in region $r$ (normalized input-output table), and $y_{rs}$ is the trade flow from region $r$ to region $s$. The emission coefficients are valid for 2001 [5, 19]. The trade time-series is valued in current prices, while constant prices (2001) are need for the analysis. To get around this issue, we only present normalized results,

$$\overline{f}_{rs}(t) = \frac{f_{rs}(t)}{\sum_r \sum_s f_{rs}(t)} = \frac{\alpha F^t{}_r y_{rs}(t)}{\sum_r \sum_s \alpha F^t{}_r y_{rs}(t)} \quad (4)$$

By normalizing the results for each year the inflation is approximately cancelled out (if $\alpha$ represents an inflation adjustment applied to $y_{rs}$ then this occurs on the top and bottom of the equation and hence cancels). The normalization also assumes that all industries and countries improve efficiency at the same rate (if $\alpha$ represents efficiency improvements applied to $F^t{}_r$ then this occurs on the top and bottom of the equation and hence cancels). While it is preferable to use constant price trade data, these assumptions do give an indication of the temporal changes.

## References

1. IPCC, *Climate Change 2007: Mitigation of Climate Change. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. O.R.D. B. Metz, P.R. Bosch, R. Dave, L.A. Meyer. 2007, Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.
2. Cole, M.A., R.J.R. Elliott, and K. Shimamoto, *Why the grass is not always greener: the competing effects of environmental regulations and factor intensities on US specialization.* Ecological Economics, 2005. **54**: p. 95--109.
3. Raupach, M.R., et al., *Global and regional drivers of accelerating $CO_2$ emissions.* Proceedings of the National Academy of Sciences, 2007. **104**(24): p. 10288-10293.
4. Peters, G.P., et al., *China's growing $CO_2$ emissions - a race between increasing consumption and efficiency gains.* Environmental Science and Technology, 2007. **41**(17): p. 5939-5944.
5. Peters, G.P. and E.G. Hertwich, *$CO_2$ Embodied in International Trade with Implications for Global Climate Policy.* Environmental Science and Technology, 2008. **42**: p. 1401-1407.
6. Weber, C.L., et al., *The Contribution of Chinese Exports to Climate Change.* Submitted, 2008.
7. Peters, G.P. and E.G. Hertwich, *Trading Kyoto.* Nature Reports Climate Change, 2008. **2**: p. 40-41.
8. Dechezleprêtre, A., M. Glachant, and Y. Ménière, *The Clean Development Mechanism and the international diffusion of technologies: An empirical study.* Energy Policy, 2008. **36**(4): p. 1273-1283.
9. Eskeland, G.S. and A.E. Harrison, *Moving to greener pastures? Multinationals and the pollution haven hypothesis.* Journal of Development Economics, 2003. **70**(1): p. 1--23.
10. Spatareanu, M., *Searching for Pollution Havens: The Impact of Environmental Regulations on Foreign Direct Investment* The Journal of Environment & Development, 2007. **16**: p. 161-182.
11. Weber, C. and H.S. Matthews, *Embodied Environmental Emissions in U.S. International Trade, 1997-2004.* Environmental Science and Technology, 2007(To appear).
12. Ahmad, N. and A. Wyckoff, *Carbon dioxide emissions embodied in international trade of goods*. 2003, Organisation for Economic Co-operation and Development (OECD).
13. Wiedmann, T., et al., *Examining the Global Environmental Impact of Regional Consumption Activities - Part 2: Review of input-output models for the assessment of environmental impacts embodied in trade.* Ecological Economics, 2007. **61**: p. 15-26.
14. Rothman, D.S., *Environmental Kuznets Curves---real progress or passing the buck? A case for consumption-based approaches.* Ecological Economics, 1998. **25**: p. 177--194.
15. Aldy, J.E., *An Environmental Kuznets Curve Analysis of U.S. State-Level Carbon Dioxide Emissions.* Journal of Environment and Development, 2005. **14**(1): p. 48--72.

16. Aldy, J.E., *Divergence in State-Level Per Capita Carbon Dioxide Emissions.* Land Economics, 2007. **83**(3): p. 353-369.
17. Suri, V. and D. Chapman, *Economic growth, trade and energy: Implications for the environmental Kuznets curve.* Ecological Economics, 1998. **25**: p. 195--208.
18. Peters, G.P. and E.G. Hertwich, *Post-Kyoto Greenhouse Gas Inventories: Production versus Consumption.* Climatic Change, 2008. **86**(1-2): p. 51-66.
19. Peters, G.P., *From Production-Based to Consumption-Based National Emission Inventories.* Ecological Economics, 2008. **65**(1): p. 13-23.
20. MNP, *China now no.1 in CO2 emissions; USA in second position*. 2007, Netherlands Environmental Assessment Agency.
21. Pauwelyn, J., *U.S. Federal Climate Policy and Competitiveness Concerns: The Limits and Options of International Trade Law*. 2007, Nicholas Institute for Environmental Policy Solutions, Duke University.
22. de Cendra, J., *Can Emissions Trading Schemes be Coupled with Border Tax Adjustments? An Analysis vis-a-vis WTO Law.* Review of European Community & International Environmental Law, 2006. **15**(2): p. 131--145.
23. Ismer, R. and K. Neuhoff, *Border Tax Adjustments: A Feasible way to Address Nonparticipation in Emission Trading*. 2004, Department of Applied Economics, University of Cambridge.
24. Pauwelyn, J. and F. Sindico, *Special issue on trade and climate.* Carbon and Climate Law Review, 2008. **1**.
25. John Kornerup Bang, Eivind Hoff, and G.P. Peters, *EU Consumption, Global Pollution*. 2008, World Wildlife Fund Trade and Investment Programme and the Industrial Ecology Programme at the Norwegian University of Science and Technology.
26. Rasmus Reinvang and G.P. Peters, *Norwegian Consumption, Chinese Pollution*. 2008, World Wildlife Fund Norway, World Wildlife Fund China and the Industrial Ecology Programme at the Norwegian University of Science and Technology.
27. Jepma, C., *Technology Transfer Bonus.* Joint Implementation Quarterly, 2008. **14**(1): p. 1-3.
28. Peters, G.P. *Is There a Role for Trade in Climate Mitigation? Measurement and Implications of Nation-State Carbon Accounting*. in *International Roundtable on Consumption-based Nation-State Carbon Accounting*. 2008. Beijing, China.
29. Stiglitz, J., *A New Agenda for Global Warming.* Economists' Voice, 2006. **3**(7): p. 1--3.