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Can Global De-Carbonization Inhibit Developing Country Industrialization?

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Abstract

Most economic analyses of climate change have focused on the aggregate impact on countries of mitigation actions. The authors depart first in disaggregating the impact by sector, focusing particularly on manufacturing output and exports because of the potential growth consequences. Second, they decompose the impact of an agreement on emissions reductions into three components: the change in the price of carbon due to each country's emission cuts per se; the further change in this price due to emissions tradability; and the changes due to any international transfers (private and public). Manufacturing output and exports in low carbon intensity countries such as Brazil are less affected. In contrast, in high carbon intensity countries, such as China and India, even a modest agreement depresses manufacturing output by 6–7 percent and manufacturing exports by 9–11 percent. The increase in the carbon price induced by emissions tradability hurts manufacturing output most while the Dutch disease effects of transfers hurt exports most. If the growth costs of these structural changes are judged to be substantial, the current policy consensus, which favors emissions tradability (on efficiency grounds) supplemented with financial transfers (on equity grounds), needs re-consideration.

This paper—a product of the Trade and Integration Team, Development Research Group—is part of a larger effort in the department to understand the policy implications of international economic integration. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The author may be contacted at amattoo@worldbank.org.

Can Global De-Carbonization Inhibit Developing Country Industrialization?

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I. Introduction

Leading up to Copenhagen, the focus of discussions has been on how much emissions should be cut and how developing countries should be compensated for any cuts they make. Accordingly, much of the literature has focused on the aggregate costs to countries of climate change mitigation actions, and the transfers that would be necessary to maintain welfare in the poorer parts of the world. However, the structural implications of these actions have received less attention.

In this paper, we seek to make a twofold contribution. On outcomes, we focus on manufacturing exports as well as on manufacturing output both in the aggregate and in selected sectors. On policy, we isolate the impact of three distinct actions—emissions reductions per se; emissions tradability; and transfers.

Why the focus on manufacturing? If it were unambiguously clear that manufacturing had no special role in the development process, and did not generate positive growth externalities, there would be no need to focus on manufacturing. A static analysis focusing on the aggregate effects of climate change actions would then be sufficient. But the literature is ambivalent: there is a body that argues in favor of positive growth benefits from manufacturing output and/or exports while others are more skeptical.[1] The paper is agnostic about both views. But insofar as there is some merit in the view that manufacturing matters, policy makers will want to take that into account, creating a need for a disaggregated analysis of the kind that we provide in this paper.

The policy disaggregation is useful because each dimension of policy may have different effects and, moreover, affect different countries differently. For example, the impact of emissions reductions varies across countries depending on the carbon intensity of their production. Furthermore, the transfers that arise from tradability themselves have growth consequences and need to be evaluated. The rich literatures on aid and growth, and financial globalization and growth are ambivalent: while many studies find either some positive or no effects, others suggest that under some conditions both public and private transfers may have negative effects on growth.[2] This paper seeks to contribute to this debate by providing some evidence on the structural impact of transfers.

The literature on the costs of climate change mitigation is voluminous and includes a number of important contributions (Cline 2007, IMF 2007, Nordhaus 2007, Stern 2007, UNDP 2007, and World Bank 2009). This literature recognizes that a regime that favors static efficiency through uniform global prices can be inequitable and therefore typically recommends financial and

[1] Recent proponents of this view include Jones and Olken (2007) and Rodrik (2009.

[2] The skeptical view of aid and growth can be found in Brautigam and Knack 2004, Collier 2007, Collier 2008, Djankov et al. 2005,; and Easterly (2007), Moyo (2009), Easterly, Levine and Roodman 2007, Elbadawi 1999, Knack 2001, Prati and Tressel 2006, Rajan and Subramanian (2008, 2010). The skeptical view of financial globalization (i.e private net flows) and growth can be found in Gourinchas and Jeanne (2007), Prasad et al. (2008) and Rogoff et al. (2004).

technology transfers to alleviate the adverse effects on developing countries (Stern (2007) and the World Bank's World Development Report (2009)). Hardly explored is the potential tension between static efficiency and dynamic effects, stemming from changes in the composition of output and exports in developing countries as a result of uniform global prices. The fact that transfers can themselves accentuate this tension through Dutch disease type effects, while acknowledged (Strand 2009), has also not been fully explored.

Hence, for many of the vital policy questions that are the subject of this paper, there are today no good answers based on empirical research. An econometric approach seems handicapped by the absence of past events and our inability to construct experiments which are comparable with the policy changes of greatest interest. We therefore use a multi-country, multi-sector CGE model to derive our quantitative estimates. In situations of simultaneous policy changes of the kind that we consider in this paper, in which there could be significant interaction among the policies of different countries, and where we are interested in quantifying the effects of policy change on output and trade in different sectors of the economy, a computable general equilibrium (CGE) approach seems appropriate (Kehoe et. al., 2005).

We focus on the case where developing countries cut their emissions by 30 per cent by 2020 relative to projected business-as-usual (BAU) levels (China already plans a 20 per cent cut in energy intensity), which may then lead industrial countries to cut their emissions by 30 per cent in 2020 relative to 2005 levels (reflecting the EU's recent conditional offer). We also consider a broad range of other scenarios.

Our main empirical findings, which come with a number of important caveats we discuss in Section IV, are the following. Some currently high carbon intensity countries/regions (such as China, India, Eastern Europe and Central Asia (ECA), and Middle East and North Africa (MENA)) will experience substantial reductions in manufacturing output and exports from emissions reductions per se.[3] For a sub-set of these countries, especially China and India, these effects will be aggravated by emissions tradability (especially on manufacturing output) and transfers (especially on manufacturing exports). For this sub-set, the negative effects will be substantial not just for carbon-intensive manufacturing but also other manufacturing sectors. For example, for China and India, the aggregate effect of all these policy actions would be a decline in manufacturing output of 6-7 percent, and in manufacturing exports by 9-11 percent. These effects would be aggravated if these developing countries pursued more ambitious emissions targets. There could also be transitional dislocation costs as resources are re-allocated across sectors.

In contrast, the manufacturing sector in low carbon intensity countries (such as Brazil and Latin America) will be less affected by actions related to climate change. In the case of sub-Saharan Africa, effects might even be positive, although any boost to manufacturing exports could be reduced through transfers and the consequent Dutch-disease-type effects.

[3] For a list of countries falling in the different groupings, see Appendix Table 1a.

These findings could have implications for the positions that countries will adopt in international negotiations. Amongst economists there is a strong consensus that the best way forward is to get a uniform global carbon price—either via a common global tax or international emissions trading—supplemented with financial transfers to address the equity dimension of climate change. This article of faith in the policy community was captured by the Financial Times in its leader of November 3 when it asserted that the price of carbon, "…must be high and the same everywhere. …In the actual world, a global scheme of tradable emissions quotas is the best solution."

If there are no growth externalities from shrunken manufacturing exports and output, this view would have considerable merit because individual countries and international cooperative efforts have to deal with only one externality—the carbon externality. But if climate change actions, by affecting manufacturing, reduce long-run growth, two externalities—carbon and growth—will have to be reconciled in ways we discuss briefly in the final section.

This paper is organized as follows. In section II, we describe the emissions reductions scenarios which we believe have greatest relevance for policy, and briefly discuss the positions that the United States (US) and European Union (EU) have taken on a key issue, the international tradability of emissions rights. In section III, we spell out the simple analytics of emissions reductions, international tradability of emissions and transfers. In section IV, we present the results of our quantitative simulations of each of the scenarios. Section V provides a concluding assessment of the implications of our result.

II. The Scenarios

Our basic scenario is one where high income countries cut their emissions by 30 percent by 2020 relative to levels in 2005, and developing countries cut their emissions by 30 percent by 2020 relative to levels in business-as-usual.[4] The 30 per cent reduction in high income countries reflects the EU's announcement that it would be willing to implement this higher cut if other countries also participated in cooperative action. Developing country reductions reflect recent statements of intent. For example, China recently announced that it plans to extend the pledge announced in its last five-year plan to cut energy use per unit of economic output by 20 per cent.[5] India too has announced a range of initiatives even though it has not yet announced a quantitative target.[6] We also consider a range of cuts by developing countries to test the robustness of our results.

In addition to emissions cuts, recent initiatives envisage international tradability of emissions rights. In the US, bills in the House and Senate differ slightly. The House version would limit the amount of total emissions rights that are internationally tradable to a maximum of one-half of the

[4] This would entail agreeing on a hypothetical baseline for emissions. However, what matters most is the binding of emissions themselves at some level that would yield a positive carbon tax.

[5] See, "Beijing in Pledge to Spur Energy Efficiency," *Financial Times*, September 23, 2009.

[6] These include a National Action Plan on Climate Change (http://moef.nic.in/downloads/home/Pg01-52.pdf) and Twenty Recent Initiatives Related to Climate Change (http://moef.nic.in/downloads/home/twenty-CC-initiatives.pdf).

2 billion tons of CO_2 that can be traded, with the remaining half being traded domestically. In the Senate version, a maximum of one-quarter of the 2 billion can be traded internationally.[7]

The Council of the European Union has recently moved in favor of international tradability. It would like to see: "preferably by no later than 2015, a robust OECD-wide carbon market through the linking of cap-and-trade systems which are comparable in ambition and compatible in design, to be extended to economically more advanced developing countries by 2020."[8]

In order to capture the effects of both emissions cuts and tradability, we consider four variants of the basic scenario (see Table 1). First, where cuts are implemented but emissions are not tradable and there are no international transfers (NTER). Second, where cuts are complemented with emissions tradability which leads to a uniform global carbon price, but we abstract from the implied private transfers (TER1); this scenario is equivalent a uniform global carbon tax regime where the taxes are retained domestically rather than being transferred across countries. The third scenario differs from the second in allowing for private transfers (TER) and this represents what will actually happen with full tradability of emissions; this scenario is equivalent to a uniform global carbon tax regime with revenues transferred across countries. Finally, we consider a scenario where supplementary public transfers are made to compensate developing countries so that they attain the same welfare levels as in the business-as-usual case (TERWMT). This might not seem realistic given the political infeasibility of generating support for large public transfers to countries such as China and India. But we use this scenario primarily as an illustrative benchmark and also to see the impact on some of the poorer countries in sub-Saharan Africa, for whom large public transfers remain politically feasible.

III. Simple analytics of Cooperative Emissions Cuts, Tradability, and Transfers

We consider first aggregate effects and then compositional effects.

Aggregate effects

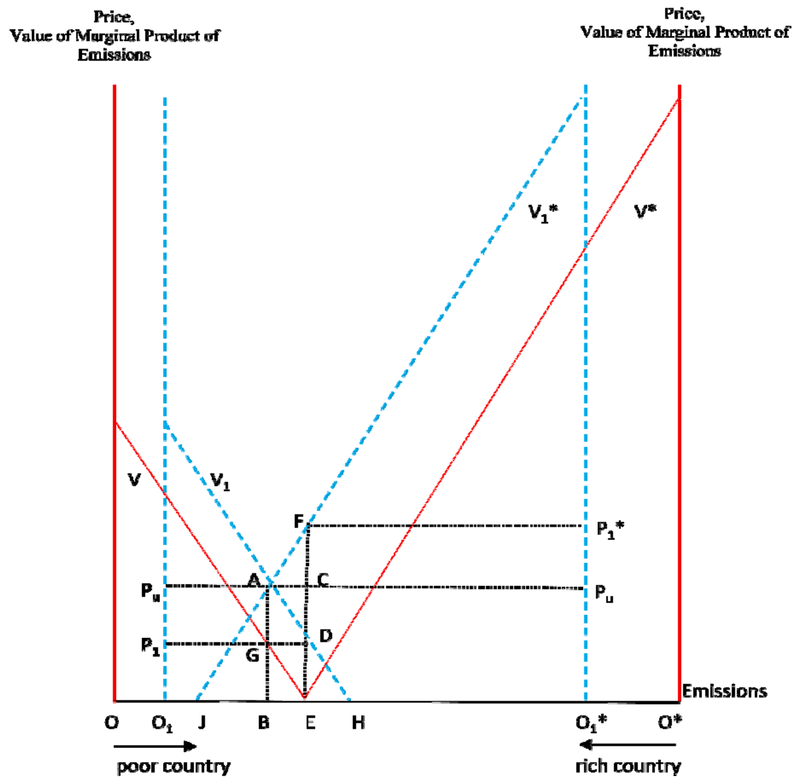
We can think of emissions (E) as an input in the production of a single composite commodity with a simple production function assumed to be given over the relatively short horizon that we consider in this paper.[9]

We depict the equilibrium for the world in Figure 1. V and V^* represent the value of marginal products of emissions (i.e., the price of the output times the marginal physical product of emissions) for the two countries, say the poor and rich, respectively. Emissions are measured from the origin O for the poor country and O* for the rich country. In the pre-emissions situation, we assume that the price of emissions is zero in both countries. In each country the equilibrium is where the marginal benefit of emissions equals the zero price of emissions. This

[7] The Senate version also has a stipulation that, after 2018, 1.25 international offset credits would be required to equal one allowance of domestic offset credit.
[8] See http://www.consilium.europa.eu/uedocs/cms_Data/docs/pressdata/en/envir/106429.pdf.
[9] See e.g. Panagariya (2009).

occurs at E, resulting in an initial level of world emissions of OO^*, with OE the emissions level of the poor and O*E the emissions level of the rich.

Figure 1: Impact of Cooperative Emissions Cuts



A global agreement on climate change will involve, first, a reduction in global emissions. Assuming that emissions in the poor country are to be reduced by OO_1 and in the rich by $O^*O_1^*$, there are two ways of achieving it: through a cap or through taxes. A cap can be represented as a shift of the origin for both countries, from O to O_1 for the poor and from O^* to O_1^* for the rich. The corresponding *V* schedules are shifted appropriately for the two countries. The price of emissions now rise to P_1^* in the rich country and P_1 in the poor. Note that this differentiated global carbon price regime could also have been achieved through differential taxes in the rich and poor respectively equal to $O^*P_1^*$ and OP_1. These emissions reductions will lead to cuts in output equal to the area DEH in the poor country and the area FEJ in the rich country (recall that output is the area under the value of marginal product curve).

The required reduction in global emissions can also be achieved through a uniform global carbon price regime. In this case, what is needed is a common tax of OP_u, which implies emissions equal to O_1B in the poor country and O_1^*B in the rich. The same outcome can be achieved by allowing international emissions tradability which would lead to arbitrage and establishment of a uniform global price equal to OP_u. This means that the price rises from P_1 to P_u in the poor country and falls from P_1^* to P_u in the rich country. Because of these price changes, there is a change in aggregate production activity in the rich and poor countries. In the latter, the sale of emission rights implies that output falls further by an amount represented by the area ABED, so that output declines overall by the area ABH. In the rich country, on the other hand, the purchase of the emission rights means that output expands by the area ABEF, so that the output declines overall by the area ABJ. In other words, tradability accentuates the emission reduction-induced output cuts in the poor country and ameliorates the output cuts in the rich country.

Of course, world output expands (by AFD) because the gains in the rich country outweigh the losses in the poor country. Tradability ensures more efficient allocation of world resources. Furthermore, tradability ensures that the loss in output for the poor country will be more than compensated by the financial transfers that will automatically occur as a result of tradability. Rich country holders of emissions permits will buy EB from holders of such permits in the poor country, resulting in a financial transfer represented by the rectangle ABEC. Net welfare in the poor country will therefore increase with tradability by the amount ACD, which is the difference between the lost output and the additional financial transfers. Conversely, in the rich country, aggregate welfare net of the transfer would rise by the triangle ACF. The world as a whole is better off.

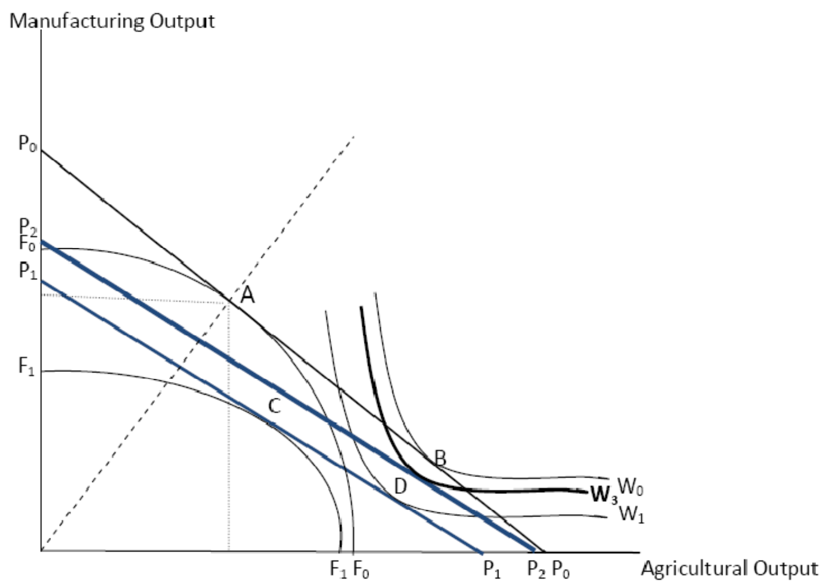
Compositional effects

In addition to the negative impact on *aggregate* economic activity, emission cuts and the tradability of emissions also affect the *composition* of economic activity. In Figure 2, F_0F_0 depicts the initial production possibility frontier (PPF) of a developing country: the economy produces manufactured (*M*) goods and other tradable goods (*A*) and faces international prices reflected in the relative price line, P_0P_0. It produces at point A and consumes at point B, attaining welfare level W_0. In this initial equilibrium, the economy exports *M* and imports *A*.

We have seen above that emission cuts combined with tradable permits lead to a contraction in the "emission endowments" of developing countries. The production of *M* is assumed to be energy intensive relative to the production of *A* (this is confirmed in Appendix Table 7 which provides data on carbon intensity of the different sectors across the world). The result of the emission cuts is an inward shift in the PPF, from F_0F_0 to F_1F_1, which is more pronounced in the vicinity of the axis measuring the output of energy-intensive *M*. With unchanged world prices, this shift is likely to lead to a cut in *M* output and increase in *A* output (which follows from the Rybczynski Theorem). But international prices are likely to change. If *M* were to become relatively more expensive (because at the global level, supply of relatively energy-intensive goods will decline) then the change in prices is likely to encourage the country's production of *M*. If the country's production of *M* is energy intensive relative to the rest of the world, then it is likely that the Rybczynski effect will dominate the relative price effect, and the share of *M* in total output will contract –i.e. the new point at which the economy produces, C, will be to the right of the line passing between the origin and the original production point, *A*.

In this new equilibrium, without any transfers, the economy consumes at D, attaining a lower level of welfare, W_1.Transfers from the rest of the world, in the form of payments for emission rights, could of course lead to an outward shift in the economy's "budget constraint" and compensate for the loss in welfare, so that post-transfers its budget line is P_2P_2, and it attains a level of welfare W_3. How far a country attains remains from its initial (pre-emission cuts) level of welfare, W_0, will depend on the magnitude of public and private transfers.

Figure 2: Resource Allocation Effects of Emission Cuts and Trading



Thus far, the analysis has focused on static effects. But emissions cuts and tradability of emission rights will also have dynamic effects through transfers and changes in the composition of economic activity. If a significant proportion of the transfers is invested in enhancing the economy's productive capacity, then it is conceivable that the contraction in the PPF could be eventually offset. But if transfers are mostly devoted to maintaining consumption, then the economy would suffer a durable contraction in productive capacity. Perhaps, more importantly, the induced shift away from manufacturing to other sectors could hurt growth if the former offers greater scope for productivity improvements than the latter.

IV. Quantifying economic effects under cooperative reductions

For many of the vital policy questions that are the subject of this paper, there are today no good answers based on empirical research. An econometric approach seems handicapped by the absence of past events and our inability to construct experiments which are comparable with the policy changes of greatest interest. In situations of simultaneous policy changes of the kind that we consider in this paper, in which there could be significant interaction effects among different countries, and where we are interested in quantifying the effects of these changes on output and trade in different sectors of the economy, a computable general equilibrium (CGE) approach seems appropriate (Kehoe et. al., 2005).

The quantitative results presented in this paper rely on a specific CGE model that has been developed at the World Bank, known as the Environmental Impact and Sustainability Applied General Equilibrium Model, or the ENVISAGE model.[10] The primary purpose of the ENVISAGE model is to assess the growth and structural impacts for developing countries from climate change itself and policies to address climate change—either unilaterally or in an international agreement.

Any quantitative analysis in this field will be conditional on assumptions regarding exogenous developments (for example the future cost of alternative technologies), key parameter values (for example intra-fuel substitution elasticities) and model specification (for example carbon tax revenue recycling). Our quantitative exercise is meant to be illustrative of the signs and broad magnitudes of effects, rather than be taken as definitive in any way. The reader should nonetheless keep in mind certain caveats regarding the model and its results.

First, and foremost, the model is not equipped to quantify any of the welfare benefits from emissions reductions per se and does not take account of emissions related to forestry.

Second, the modeling does not take into account any pre-existing subsidies or other distortions in developing country energy markets whose elimination could provide opportunities for emission abatement. The OECD (2009) has calculated the fuel subsidies in a number of developing economies. Most of these are consumption rather than production subsidies and, although they vary across fuel types and income groups, their average value is relatively low (for example, less than 3 percent for China). This suggests that eliminating these subsidies will have positive welfare consequences that our results do not incorporate. However, the fact that the magnitudes are low would suggest that our results relating to compositional changes may not be significantly affected.

Third, the model is not able to represent the full range of available alternative technologies, and so may tend to exaggerate the output and trade responses as energy prices rise with emission limits. But some features of the model may limit the biases on this score. We allow for exogenous improvements in manufacturing energy efficiency through the accumulation of more advanced capital stock. Also, the current version of the ENVISAGE model does allow for limited substitution between technologies. For example, it allows for switching to alternative (and cleaner) technologies in the power sector, albeit in limited fashion.[11] The model also allows

[10] The model has several distinguishing features: a focus on developing countries and significant sectoral disaggregation; an integrated climate module that generates changes in global mean temperature based on emissions of four greenhouse gases; and economic damage functions linked to changes in temperature. A summary description of the model and the key assumptions are provided in the Technical Appendix and van der Mensbrugghe (2009) provides a full description of the model.

[11] The current electricity technologies include five activities—coal, oil and gas, hydro, nuclear and other (essentially renewable). The five activities are aggregated together to 'generate' a single electricity commodity distributed to

for some substitution to natural gas in the transportation sector but not to biofuels and only to a limited extent to electricity (to the extent some modes of public transportation already rely on electricity).

The limited possibilities for technological substitution may not be unrealistic given that our horizon is relatively short-term: we are projecting economic magnitudes for 2020, about ten years out from today. Also, the emission taxes and the consequential price changes in our model are relatively small. For example, in the most extreme scenario, when both high and low income countries reduce emissions, the overall price of energy rises by 41 percent in China and 26 percent in India. These prices are not large enough to induce large technology switching responses. For example, Birdsall and Subramanian (2009) find that it took the oil price shock of the 1970s—which involved a quadrupling of energy prices—to induce a small response in energy efficiency in production and even more modest response on the consumption side.

Quantitative effects

Even within developing countries, the impact of emission reductions is likely to differ for regions where the carbon intensity of production is high, and other regions where it is relatively low. As Appendix Table 7 shows, the high carbon-intensity group clearly includes China, India, Russia and the rest of Eastern Europe and Central Asia (ECA) (all with economy-wide carbon intensities higher than 500 tons per million dollars), and possibly the Middle East and North Africa (MENA) (at 380 tons per million dollars).[12] The relatively low carbon intensity group clearly includes Brazil and the Rest of Latin America (LAC) (with economy wide carbon intensities lower than 200 tons per million dollars). Finally, there is an intermediate group, which includes Sub-Saharan Africa (SSA), Rest of South Asia (SA), and Rest of East Asia (EA) (with economy-wide carbon intensities between 280 and 332 tons per million dollars). We focus on the first group, especially China and India, because these countries are likely to be subject to the most significant effects, then describe how effects differ for the second group, focusing on Brazil, and finally turn to the intermediate group, focusing on SSA.

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households and producers. The 'aggregator' (for example the electricity distribution sector) chooses the least cost supplier subject to a CES aggregation function (that is calibrated to base year shares). Thus the coal producer will see a decline in demand relative to other producers—particularly hydro, nuclear and other—when subject to the carbon tax. The amount of the shift will depend on both the overall demand elasticity as well as the base year share. In the current baseline, these shares are fixed at base year levels. It is clear that there are non-price factors that are pushing these shares in one direction or another and we are witnessing rapid rises (from a very low base) in renewable technologies (notably wind and solar). In the model, and in reality, expansion of hydro is limited to physical potential. We make no effort to model changes in the share of nuclear power. In addition, the model ignores one potentially significant change in power generation and that is the introduction of carbon capture and storage (CCS) for coal and gas powered thermal plants. However, CCS is unlikely to become a major technology before 2020 (though its anticipation could affect investment decisions in the near term). CCS may also be a feasible technology in some other fossil-fuel dependent sectors such as cement and iron and steel production.

[12] Production could be relatively carbon intensive in developing countries for these broad GTAP categories both because individual products are produced more carbon-intensively and because the broad product categories include more carbon-intensive products.

Category 1: High carbon intensity countries (China, India, Russia, ECA and MENA)

We consider the impact on this group of countries in each of the four scenarios described in Section II. In the first scenario, when cuts are implemented without the possibility of international trade in emission rights (the "NTER" scenario), our simulations suggest that the average carbon price in high income countries rises to $478 per ton of carbon and to $92 per ton of carbon in low and middle income countries (LMICS).[13] Aggregate welfare would fall by 2.2 percent relative to the baseline in all LMICs, with relatively larger welfare losses in the oil exporting regions such as Russia and the Middle East, and somewhat smaller reductions in the large emitters such as China and India (Table 3).

Manufacturing exports decline by 4.5 percent in China and 7.3 percent in India. The corresponding declines in manufacturing output are 2.9 percent and 3.7 percent, respectively (Table 4).[14] The main reason for these declines is that manufacturing is the most carbon-intensive sector, after the energy sector itself, and so is worst hit by carbon price increases.

In the second scenario (TER1), tradability leads to a uniform global carbon price (of $133 per ton (Appendix Table 2)) but we abstract from the private transfers that would result from tradability. Recall that this scenario is equivalent a uniform global carbon tax regime where the taxes are retained domestically rather than being transferred across countries. In this case, welfare losses increase substantially, especially for China from 1.8 percent to 3.8 percent, and for India from 1.5 percent to 2.1 percent (see scenario TER1 in Table 3). Manufacturing output declines further to 5.8 and 5.2 percent, respectively in China and India.

Allowing transfers (along with tradability), as expected, alleviates the welfare declines seen in the non-tradability scenario (see scenario TER in Table 3).[15] However, it magnifies the impact especially on manufacturing exports via Dutch disease-type mechanisms. For example, China's manufacturing exports fall by 9.4 percent and India's by 10.7 percent. The pure effect of the private transfers (the difference between the TER1 and TER scenarios) is to induce a further decline in exports amounting to 3.6 percent for China and 2.1 percent for India.[16]

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[13] All prices are measured in terms of $2004 per ton of carbon. The price per ton of CO_2 can be obtained by dividing the carbon price by approximately 4 (or more precisely by 44/12≈ 3.67).

[14] Russia is an exception in this group of countries because it's manufacturing output and exports increase in the NTER scenario (Appendix Tables 5 and 6). The reason is that when all countries cut their emissions, there is a significant contraction in global demand for energy; energy accounts for a large share of the Russian economy (53 per cent of its exports and 24 per cent of its output, as shown in Appendix Table 8); the contraction in demand induces a significant shift in resources away from Russia's energy sector and towards other sectors, including manufacturing.

[15] The magnitude of this effect depends of course on the quota allocation scheme.

[16] In our model, Dutch disease effects from transfers arise mainly from the condition that the external accounts must be balanced, which is a plausible description of long run equilibrium. Are these effects from transfers plausible? In the case of China, for example, the results suggest that a transfer of about 1.8 percent of GDP would depress manufacturing export growth by about 0.5 percent. This is well within the range obtained from econometric estimates: Rajan and Subramanian (2010) find that a 1 percent increase the aid-to-GDP ratio tends to reduce overall manufacturing growth by close to 1 percent.

The other high carbon intensity countries in regions such as MENA and ECA suffer output and export reductions due to the emissions reductions just as in China and India.[17] But the former group does not suffer much from emissions tradability and the implied private transfers. The magnitude of transfers will depend on the wedge between the domestic carbon price prevailing after emission cuts and the uniform global price that will prevail with tradability. For MENA and ECA, the former is close to the latter, so that tradability leads to a small price change and hence also to a small private transfer.

If developing countries were to receive additional official transfers to compensate for the loss of welfare caused by emissions reductions, then the Dutch disease type effects would be even stronger (see scenario TERWMT in Table 3). Manufacturing exports would decline by 12 percent and 15 percent, respectively for China and India. The corresponding figures for manufacturing output are 7 percent and 6 percent, respectively. As we mentioned earlier, these transfers are unlikely to materialize for the larger developing countries but cannot be ruled out for poorer countries. To maintain welfare, the EU, Japan and US would be required to make total transfers (public and private) equal to about 1 per cent of their GDP – a figure similar to the recent demands made by developing countries.

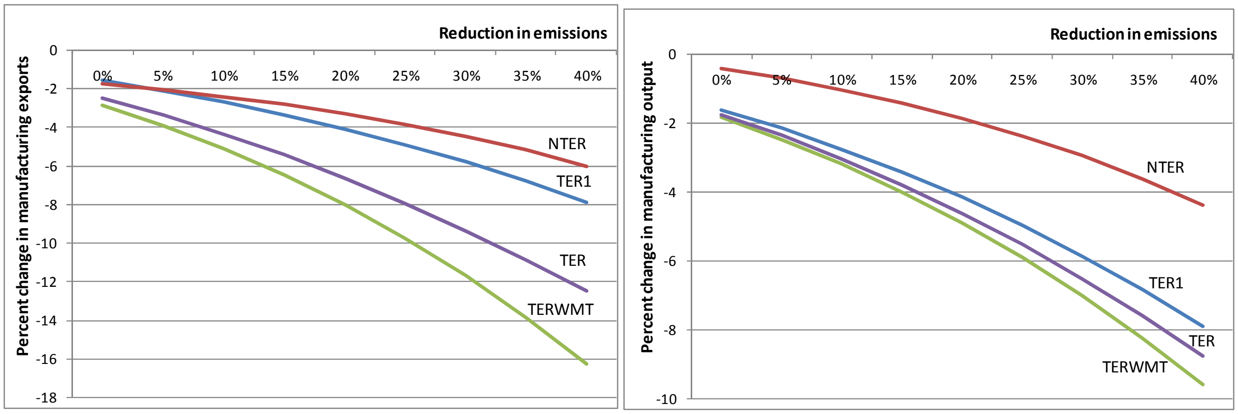
In sum, emission limits with tradability create a dilemma for this group of countries: tradability leads to a contraction in the manufacturing sector and the more the country seeks to maintain static welfare, the higher the price it will pay in terms of further contraction of this sector.

Generalizing the results to other scenarios

Are these results unique to the assumptions we have made about the extent of emissions reductions by developing countries? In Figures 3 and 4, we show the consequence of replicating the analysis described above for a range of emissions reduction by developing countries—from no emissions reduction (relative to BAU) to a 40 percent cut – keeping the emissions reduction by high income countries fixed at 30 percent below 2005 levels. For China and India, for example, we find results consistent with the findings described earlier.

[17] Russia is different from the other countries in that the global emission reduction leads to an increase in its manufacturing output. The reason is that energy accounts for a large share of its exports and output, and a contraction in global demand for energy induces a shift in resources away from this sector towards manufacturing.

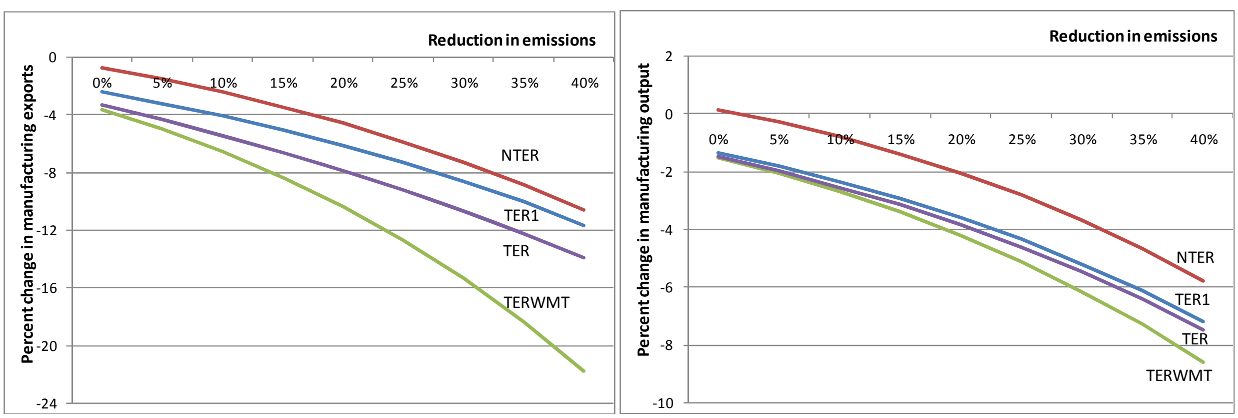
Figure 3: Impact on China's Manufacturing Exports and Output of Emissions Reductions by All Developing Countries (% change, relative to BAU in 2020)



Note: Emissions reductions by high income countries are fixed at 30 percent below 2005 levels.

Several features are noteworthy about these figures. First, as expected, the greater the emissions reductions by these countries the greater the decline in their manufacturing exports and output. More interesting are the respective consequences of tradability and transfers which are captured by the gap between the different lines in the graph.

Figure 4: Impact on India's Manufacturing Exports and Output of Emissions Reductions by All Developing Countries (% change relative to BAU in 2020)



Note: Emissions reductions by high income countries are fixed at 30 percent below 2005 levels.

For *exports*, significant adverse impacts arise from the Dutch disease type effects of transfers (see in Figures 3 and 4 the difference between TER1, which involves no transfers, and TER, which allows private transfers, or TERWMT, which allows also public transfers). For China, the incremental effect of private transfers increases with the level of emissions reductions (gap between TER and TER1 scenarios widens).[18] Note that a 40 percent emissions reduction relative

[18] The magnitude of transfers for any country is the product of the international price of carbon and its own sales/purchases of emissions. The international price rises with deeper emissions cuts by developing countries. The sales/purchases will depend on the wedge between the domestic and international price of carbon. In the case of

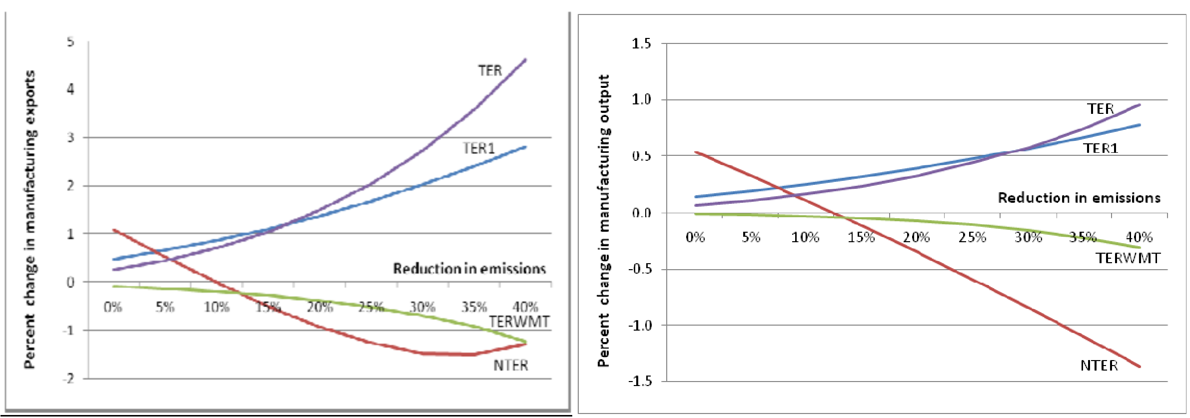
to BAU still represents an increase in emissions relative to 2005. If developing countries had to start ensuring even stabilization of carbon emissions by 2020, the implied effects on manufacturing exports, based on extrapolating the trends shown in Figures 4 and 5, would be enormously large.

For *output*, the significant adverse effects arise from the economy-wide carbon price-increasing effects of tradability (see in Figures 3 and 4 the difference between NTER, which assumes emissions are not tradable, and TER1, which assumes emissions are tradable). In fact, even if India and China made no cuts in emissions but bound emission levels at BAU levels and allowed international tradability, each would see a decline in manufacturing output of about 1.5 percent.

Category 2: Low Carbon Intensity Countries (Brazil and LAC)

The effects on the manufacturing sector of low carbon intensity countries from policy actions related to climate change are likely to be different from those on high carbon intensity countries. There are two counteracting factors. First of all, any change in the price of carbon affects manufacturing output and competitiveness less in these countries because of their low carbon intensity. Brazil's total carbon intensity, for example, at 168 dollars per ton (Appendix Table 7) is about one-quarter and one-third of China's and India's, respectively. Secondly, reductions in emissions require progressively higher carbon price increases in these countries, in large part because their production is already relatively clean and it is harder for them to squeeze out deeper and deeper reductions. For example, to achieve a 5 per cent reduction, Brazil's carbon price would need to be \$43; but to achieve a 30 per cent reduction in emissions, Brazil's carbon price would need to increase to \$376 per ton of carbon, more than four times the required level in India, and nine times the required level in China (Appendix Table 3).

Figure 5: Impact on Brazil's Manufacturing Exports and Output of Emissions Reductions by All Developing Countries (% change relative to BAU in 2020)



When only small cuts are made in emissions reductions by developing countries, the positive effect on Brazil's manufacturing sector of its relatively low carbon intensity dominates the

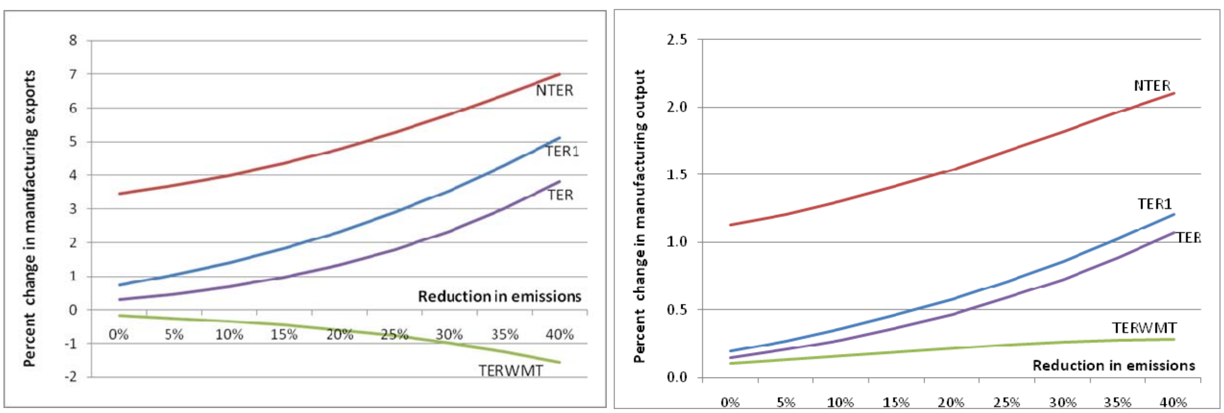
China, this wedge narrows more gradually—and hence the volume of its emissions sales declines gradually—because of its greater carbon intensity.

negative effect due to its higher carbon price (see NTER in Figure 5). But when larger cuts are made, the converse is true – the large increases in carbon price overwhelm the benefits of low relative carbon intensity - so that Brazil's manufacturing exports and output decline. If trade in emissions rights is allowed, Brazil enters the market at low levels of emissions reductions as a seller but at higher levels of emission reductions as a buyer – like the high income countries. The result in the latter situations is a decline in the carbon price toward the global uniform price and private outflows, both of which benefit the manufacturing sector (see TER1 and TER in Figure 5).

Category 3: Intermediate Carbon Intensity Countries (Sub-Saharan Africa, Rest of South Asia, and Rest of East Asia)

The impact on SSA, SA and EA is broadly intermediate between those on the high and low carbon intensity economies, and we focus here on SSA.[19] The SSA manufacturing sector actually expands if all developing countries cut their emissions by 30 per cent (see NTER in Figure 6). The reason is primarily SSA countries' low carbon intensity in manufacturing, which combined with the lower emissions tax consequent upon emissions reductions, actually improves competitiveness relative to other countries.

Figure 6: Impact on Sub-Saharan Africa's Manufacturing Exports and Output of Emissions Reductions by All Developing Countries (% change relative to BAU in 2020)



However, if SSA countries receive large public transfers to compensate for loss in welfare (1.5 percent), then they could experience an adverse export effect from a Dutch disease-type mechanism. The negative effect of transfers (the gap between TER and TERWMT in Figure 6) on manufacturing exports could be close to 4 percent - unless these transfers were successfully invested in ways that enhanced productivity in manufacturing or reduced trade costs.

[19] EA resembles Brazil in that emissions reductions require a high carbon price due to their already relatively clean production. Therefore, emissions trading leads to a decline in the carbon price which benefits manufacturing.

Changes in the composition of manufacturing

It is clear that the bigger impacts are in energy-intensive manufacturing, but countries may also be interested in the impacts on other manufacturing sectors (which includes clothing, electronics and transport equipment). The trade-off between carbon and long-run growth effects could be different between these sectors. For example, if the dynamic growth effects are less strong in energy-intensive sectors than in other manufacturing sectors, and if the latter are not substantially affected by emissions reductions and emissions tradability, international commitments on emissions reductions should raise fewer growth concerns.

In countries like China and India, the impact of emissions reductions and tradability on the category "other manufacturing" will also be substantial (Appendix Tables 5 and 6). Output will decline by 5 percent and 3.3 percent, respectively for the two countries, and exports by close to 7 percent for both countries. For other countries such as Brazil, East Asia and sub-Saharan Africa, the impact on the output of other manufacturing sectors will be relatively modest. It is noteworthy that Dutch disease effects will remain strong for exports of other manufacturing sectors in China, India and sub-Saharan Africa. For China and India, the effect of private transfers per se is to induce a decline in exports of 3.7 and 2.4 percent, respectively. For sub-Saharan Africa, the effect of private and public transfers is to induce a 5.2 percent decline in other manufacturing exports.

Overall, the preceding results suggest that the interests of developing countries might diverge in relation to some of the key issues in the climate change negotiations. The differences between countries in terms of the impact on the manufacturing sector are the following. High carbon intensity countries (China, India, ECA and MENA) will be more resistant to emissions reductions than low carbon intensity countries (Brazil, LAC, East Asia) because of the impact on both manufacturing output and exports. Some high carbon intensity countries (especially China and India) will also be resistant to emissions tradability because of the further negative impact on output and of the impact of the resulting private transfers on manufacturing exports. Low carbon intensity countries will not be averse to emissions tradability. For Sub-Saharan African countries, a potential negative effect could stem from the effect of public transfers on manufacturing exports, unless these transfers could be successfully invested in ways that enhanced productivity in manufacturing or reduce traded costs.

Cost of dislocation

Thus far, we have focused on the impact of emissions reductions on the composition of output and exports. There are also likely to be dislocation costs as resources are re-allocated across sectors, and the nature of these dislocations will differ between high and low income countries. For example, in the US and EU, all nine manufacturing sectors in our model are likely to expand as a result of international tradability of emissions; in contrast, in China, eight of the nine sectors are expected to see a decline in output (refined oil, chemicals, rubber and plastics, paper products and publishing, mineral products, ferrous metals, other metals, transport equipment, and other manufacturing). In India, seven out of the nine sectors are likely to see a decline in output. If some factors are sector-specific and imperfectly mobile (which is assumed away in the model), then the transition to any new equilibrium could lead to at least temporary unemployment. The irony is that high income countries, which typically have better social protection mechanisms, are less likely to need to deal with the contraction of tradable sectors.

V. Discussion and Conclusions

With an increasing number of countries accepting the need for action to address climate change, both the prospects for and the impact of cooperative emissions reductions are receiving significant attention. This paper has attempted, and provided a methodological tool, to quantify the impact of cooperative policy actions related to climate change on the manufacturing sector in developing countries. It has departed from the existing work on climate change in two ways. First, we have disaggregated the policy actions into emission reductions per se, international emissions tradability, and international transfers. Second, in terms of outcomes, instead of focusing on aggregate output, we quantify the effects on manufacturing output and exports.

These distinctions are important for a number of reasons. The heterogeneity of developing countries means that different types of policy action may have different effects and a disaggregation is crucial to understanding this heterogeneous response. The focus on the manufacturing sector and sub-sectors stems from the need to take into account the possibility that manufacturing output and exports could affect long-run growth performance.

Our key findings, which come with all the caveats that we have noted, are the following. Some currently high carbon intensity countries/regions (such as China, India, ECA and MENA) will experience substantial reductions in manufacturing output and exports from emissions reductions per se. For a sub-set of these countries, especially China and India, these effects will be aggravated by emissions tradability (especially on manufacturing output) and transfers (especially on manufacturing exports). For this sub-set, the negative effects will be substantial not just for carbon-intensive manufacturing but also other manufacturing sectors.

In contrast, the manufacturing sector in low carbon intensity countries (such as Brazil and Latin America) will be minimally affected by the actions related to climate change. In the case of sub-Saharan Africa, effects might even be positive, although any boost to manufacturing exports could be reduced through transfers and the consequent Dutch disease-type effects. Of course, if private and public transfers are able to raise productivity and reduce trade costs, then these effects could be offset.

These findings could have implications for the positions that countries adopt in international negotiations on climate change. If there are no growth externalities from shrunken manufacturing exports and output, policy choices are simpler because individual countries and international cooperative efforts have to deal with only one externality—the carbon externality. But if climate change actions, by affecting manufacturing, reduce long-run growth, two externalities—carbon and growth—will have to be reconciled.

For low carbon intensity countries, the results suggest that there is little tension between the two externalities because the impact of climate change actions on the manufacturing sector is limited. For sub-Saharan Africa, there might be a tension related to transfers which would need to be addressed.

But for high carbon intensity countries (especially China, India, ECA and MENA), whose manufacturing exports and output will be substantially affected, the choice may be more difficult. This choice can have several dimensions. For example, countries will have to determine where specifically the long run growth externality resides. If it is primarily in non-energy intensive manufacturing sectors, developing countries can justifiably resist international obligations that adversely affect these sectors. If energy-intensive sectors also have positive long-run benefits, the reconciliation between the carbon and growth externalities becomes more difficult.

A second dimension relates to policy instruments. If two externalities need to be addressed, two policy instruments will need to be deployed. The first-best solution might then be to tax the carbon externality appropriately (by taking on international obligations on emissions reductions and tradability) while addressing the manufacturing externality through a combination of production subsidies (if the externality lies in manufacturing output) or export subsidies (if the externality lies in manufacturing exports). For developing countries, this first best solution will encounter two problems. First, WTO rules prohibit the use of export subsidies and production subsides can be legally countervailed by trading partners. Unless, these rules are relaxed, the first-best response is not possible. A second, arguably bigger, problem is the difficulty of implementing subsidies: the experience with industrial policies and "picking winners" has highlighted the demanding requirements for successfully doing so. Thus, if implementation capacity is limited and countries find themselves in a second-best world, the reconciliation of the two externalities becomes more difficult.

In this second-best world, one option for countries then would be to use one instrument but to strike a balance between the two objectives. So, if countries cannot implement subsidies to capture the growth externality, they may choose to allow some increase in carbon prices (consequent upon say domestic emissions reductions) but not to allow any further increase (resulting from emissions tradability). This suggests that selection from the menu of options within the climate change regime itself could be a possibility for high carbon intensity developing countries.

Of course, any policy choices made by developing countries that depart from the first-best of fully taxing the carbon externality would lead to a non-uniform regime for carbon prices and hence make developing countries vulnerable to trade action. This cost could be minimized if developing countries could persuade their industrial country partners as part of a comprehensive agreement on climate change to take no trade actions (described in a companion paper, Mattoo et al. 2009). Actions based on the carbon content of imports and applied across-the-board could have serious trade consequences, implying average tariffs on India and China of over 20 percent.

Finally, a much larger issue relates to the sources of long-run economic dynamism. Thus far, we have discussed the carbon externality as being at odds with the growth externality for the high carbon intensity countries such as China and India. But if their future growth potential lies in non-energy intensive sectors and in green technologies, these countries need to be less concerned about preserving energy-intensive manufacturing and more eager to create the incentives to facilitate the necessary transition. In this case, the carbon and growth externalities would not be at odds in the policy choices but mutually reinforcing.

Given the considerable uncertainty about the optimal policy from a growth perspective, a key question is whether it is possible to devise a hedging strategy that creates incentives for technology generation and adoption in new green sectors without sacrificing the existing manufacturing sector. Many developing countries, including China, India, and South Africa, are increasingly paying much higher prices for renewable sources of energy than for carbon-based sources. The relative price changes induced in this manner may have a less disruptive effect on downstream users of energy than an increase in carbon prices, with the government absorbing the dislocation costs that would otherwise be imposed on the private sector. Another option could involve non-price-based mechanisms such as funding R&D directly, instituting advance market commitments (see Kremer and Glennerster 2004) or through government procurement. More research is needed to determine whether these alternatives can achieve the desired goals.

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Table 1: Scenarios for Cooperative Emissions Reductions

Description of Scenarios	Target Emisions Cuts		Transfers
	High Income	Low and Middle Income	
Both industrial and developing countries reduce emissions but emissions rights are not tradeable (NTER)	30% relative to 2005 emission levels	30% relative to business-as-usual levels	No
Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers (TER1)	30% relative to 2005 emission levels	30% relative to business-as-usual levels	No
Both industrial and developing countries reduce emissions and emissions rights are tradeable (TER)	30% relative to 2005 emission levels	30% relative to business-as-usual levels	Yes, through emissions trading
Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions reductions (TERWMT)	30% relative to 2005 emission levels	30% relative to business-as-usual levels	Yes, through public transfers and emissions trading

Table 2: Impact on Emissions Reductions

Scenario	World Total	High Income	US	EU	Low and Middle Income	China	Brazil	India	SSA
% Change in Emissions Relative to Business as Usual (BAU) in 2020									
NTER	-33.8	-40.9	-43.9	-40.9	-30.0	-30.0	-30.0	-30.0	-30.0
TER1	-33.8	-18.8	-21.4	-14.8	-41.9	-50.5	-14.9	-38.0	-42.3
TER	-33.8	-42.3	-21.5	-15.0	-41.8	-50.4	-15.0	-38.0	-42.3
TERWMT	-33.8	-42.0	-21.8	-15.5	-41.6	-50.4	-15.0	-37.9	-42.0
% Change in Emissions Relative to 2005									
NTER	14.5	-26.5	-30.0	-30.0	54.3	97.3	-5.0	78.0	24.0
TER1	14.5	0.4	-1.9	1.1	28.0	39.6	15.6	57.6	2.2
TER	14.5	0.2	-2.1	0.8	28.2	39.9	15.4	57.7	2.3
TERWMT	14.5	-0.2	-2.4	0.1	28.6	39.8	15.4	58.0	2.8

Notes: ***NTER:*** *Both industrial and developing countries reduce emissions but emissions rights are not tradeable;* ***TER1:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers;* ***TER:*** *Both industrial and developing countries reduce emissions and emissions rights are tradeable;* ***TERWMT:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions*

Scenario	World Total	High Income	US	EU	Low and Middle Income	China	India	Brazil	SSA
% Change in Welfare									
NTER	-1.5	-1.2	-1.3	-1.3	-2.2	-1.8	-1.5	-1.4	-1.9
TER1	-0.9	-0.2	-0.2	-0.1	-2.6	-3.8	-2.1	-0.5	-2.0
TER	-0.9	-0.5	-0.7	-0.4	-1.7	-1.5	-1.5	-0.8	-1.5
TERWMT	-0.8	-1.2	-1.1	-1.4	0.0	0.0	0.0	0.0	0.0
% Change in Output of Total Manufacturing									
NTER	-1.7	n.a.	-1.3	-0.7	-2.5	-2.9	-3.7	-0.8	1.8
TER1	-1.6	n.a.	0.0	0.5	-4.0	-5.8	-5.2	0.6	-5.2
TER	-1.5	n.a.	0.8	0.7	-4.4	-6.5	-5.5	0.6	0.7
TERWMT	-1.4	n.a.	1.6	1.3	-5.0	-7.0	-6.1	-0.2	0.3
% Change in Exports of Total Manufacturing									
NTER	-2.9	-2.4	-2.3	-1.9	-3.5	-4.5	-7.3	-1.5	5.8
TER1	-1.8	0.2	0.1	1.2	-3.9	-5.8	-8.6	2.0	3.5
TER	-1.9	1.6	2.7	2.6	-5.6	-9.4	-10.7	2.7	2.3
TERWMT	-1.9	3.9	5.0	6.5	-8.3	-11.7	-15.4	-0.7	-1.0

Table 3: Impact on Welfare, Manufacturing Output, and Exports

Notes: Changes are expressed relative to business-as-usual in 2020; ***NTER:*** *Both industrial and developing countries reduce emissions but emissions rights are not tradeable;* ***TER1:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers;* ***TER:*** *Both industrial and developing countries reduce emissions and emissions rights are tradeable;* ***TERWMT:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions*

Technical Appendix: The Model

The results in this paper rely on the World Bank's Environmental Impact and Sustainability Applied General Equilibrium (ENVISAGE) Model.[20] The ENVISAGE model's core is a relatively standard recursive dynamic global general equilibrium (CGE) model. Incorporated with the core CGE model is a greenhouse gas (GHG) emissions module that is connected to a simple climate module that converts emissions into atmospheric concentrations, radiative forcing and changes in mean global temperature. The climate module has feedback on the economic model through so-called damage functions—currently limited to productivity shocks in agriculture. The combination of the socio-economic CGE model with the climate module is commonly referred to an integrated assessment model (IAM).

ENVISAGE is calibrated to Release 7 of the GTAP dataset with a 2004 base year.[21] It has been used to simulate dynamic scenarios through 2100. For the purposes of this study, 2020 is the terminal year. The 113 countries/regions of GTAP are aggregated to 15 countries/regions for this study and the 57 sectors are aggregated to 21 sectors. Full detail on the aggregation is provided in Appendix Table 1. The GTAP data is supplemented with satellite accounts that include emissions of the so-called Kyoto gases—carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (F-gases), different electricity production activities (coal, oil and gas, hydro, nuclear and other), and potential land and hydro supplies.

Within each time period a full equilibrium is achieved given the fixed regional endowments, technology and consumer preferences. Production is modeled as a series of nested constant-elasticity-of-substitution (CES) functions that are designed to reflect the substitution and complementarity of inputs. Unlike many standard models, energy plays a key role as an input and is modeled as a complement to capital in the short-run but a substitute to capital in the long run. This reflects the putty/clay specification of production that incorporates vintage capital. The key assumption is that there is greater substitution across inputs in the long run (i.e. with *new* capital) than in the short run (with *old* or installed) capital. One consequence of this specification is that countries that have higher growth and higher rates of investment typically have a more flexible economy in the aggregate. Thus, all else equal, the same tax on carbon has a lower cost. There is a single representative household that consumes goods and services and saves.[22] The savings rate is partially a function of the demographic structure of the region. Savings rise as either the elderly or youth dependency ratios fall. The government sector is relatively passive. Aggregate expenditures are fixed as a share of total GDP and revenues adjust to maintain fiscal balance (through a lump sum tax on households). Investment is savings driven.

Aggregate demand by sector is summed across all domestic agents and represents a composite of domestically produced goods and imports—the so-called Armington aggregate.[23] The aggregate Armington good is allocated between domestic production and imports using a two-nested CES specification. The first nest allocates aggregate demand between domestic production and an aggregate import bundle. The second nest decomposes aggregate imports into import by region of origin. This generates a bilateral trade flow matrix. Domestic producers are assumed to supply both domestic and export markets without friction, i.e. the law of one price holds for domestically produced goods irrespective of their final destination.[24] Bilateral trade is associated with

[20] See van der Mensbrugghe 2008 for full details of the model.
[21] See www.gtap.org.
[22] The model is designed with several different consumer demand specifications including the CDE (see Hertel 1997), the LES/ELES (see van der Mensbrugghe 2006) and the AIDADS (see Rimmer and Powell 1992 and van der Mensbrugghe 2006). For this paper we have used the AIDADS.
[23] Armington 1969.
[24] Analogously to aggregate domestic demand, the model allows for a two-nested constant-elasticity-of-transformation function to allocate domestic production between domestic and foreign markets.

three price wedges. The first wedge reflects differences between producer prices and the border (FOB) price, i.e. an export tax or subsidy. The second wedge reflects international trade and transport margins, i.e. the difference between FOB and CIF prices. The third wedge reflects the difference between the CIF price and the end-user price, i.e. import tariffs. All three wedges are fully bilateral.

Model closure is consistent with long-term equilibrium. As stated above, fiscal balance is maintained through lump sum taxes on households under the assumption of fixed public expenditures (relative to GDP). Changes in revenues, for example carbon tax revenues, imply a net decrease in household direct taxes. Investment is savings driven. This assumption implies that changes in investment are likely to be relatively minor since public and foreign savings are fixed and household savings will be relatively stable relative to income. The third closure rule is that the capital account is balanced. Ex ante changes in the trade balance are therefore offset through real exchange rate effects. A positive rise in net transfers, for example through a cap and trade scheme, would tend to lead to a real exchange rate appreciation.

The model dynamics are relatively straightforward. Population and labor force growth rates are based on the UN population's projection[25]—with the growth in the labor force equated to the growth of the working age population. Investment, as mentioned above, is savings driven and the latter is partially influenced by demographics. Productivity growth in the baseline is 'calibrated' to achieve a target growth path for per capita incomes—differentiated for agriculture, manufacturing and services.

Emissions of GHGs have three drivers. Most are generated through consumption of goods—either in intermediate of final demand—for example the combustion of fossil fuels. Some are driven by the level of factor input—for example methane produced by rice is linked to the amount of cultivated land. And the remainder is generated by aggregate output—for example waste-based methane emissions. The climate module takes as inputs emissions of GHGs and converts them to atmospheric concentration, then radiative forcing and finally temperature change.[26]

The temperature change is linked back to the socio-economic model through damage functions. The damage functions—currently limited to agriculture—are calibrated to estimates provided by Cline (2007). His estimates relate to anticipated productivity impacts from a 2.5° C in temperature[27], estimated to occur according to his estimates in 2080. Cline provides two sets of estimates. One set allows for the positive impact of higher concentrations of CO_2 in the atmosphere on plant growth—a so-called carbon fertilization effect. The other excludes this effect. The scientific community is still uncertain about this effect. Greenhouse gas experiments suggest it may be potent. Field experiments suggest otherwise. In our simulations, we use the average of the two estimates.

ENVISAGE has a flexible system of mitigation policies (limited to the moment to CO_2 emissions alone). The simplest is a country or region specific carbon tax—that also allows for exemptions for designated sectors or households. An alternative is to provide a cap on emissions at either a country, regional or global level. The model will then produce the shadow price of carbon, i.e. the carbon tax, as a model outcome. If a global cap is imposed, a single uniform tax will be calculated. This type of regime assumes no trading. A final option is to have a regional or global cap with trading and assigned quotas. Similar to the previous regime, a uniform carbon tax will be calculated (and would be nearly identical to the no-trade carbon tax), but emissions trading would occur depending on the initial quotas and the shape of the individual marginal abatement curves for each member of the trading regime.

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[25] United Nations 2007.

[26] The climate module is largely derived from the MERGE model, Manne et al 1995.

[27] Which he assumes occurs in the 2080s based on the SRES scenarios (IPCC 2000) and global climate change model (GCM) runs.

One intuitive way to capture the inter-country differences of a carbon tax is the following formula that is derived from a simple partial equilibrium framework:[28]

$$(1) \qquad R = 1 - \left[1 + \frac{\rho.\tau}{P}\right]^{\sigma} \leftrightarrow \tau = \frac{P}{\rho}\left[(1-R)^{-1/\sigma} - 1\right]$$

In formula (1), τ is the carbon tax, P is the price of energy (for example $ per ton of oil equivalent), ρ is the average carbon content of energy (for example ton of carbon per ton of oil equivalent), σ is the overall elasticity of substitution across factors include energy and R is the level of emissions reduction.[29] The left hand side of the formula shows the level of reduction for a given carbon tax and the right hand side shows the level of the carbon tax for a given reduction level. With R equal to 0, the carbon tax is obviously 0. The formula suggests that the carbon tax is higher (for a given targeted reduction) with higher energy prices, lower carbon content (i.e. cleaner economies) and less flexible economies (i.e. with a low value for σ). This suggests that the carbon tax will be higher on average in developed economies that already have high energy prices and relatively clean energy (for example France and Japan) and have lower savings and therefore more installed and less flexible capital than on average in the rapidly developing economies. The implication of this is that on aggregate developed countries will wish to purchase carbon offsets from developing countries in a cap and trade regime where quotas for developed countries are below baseline emissions.

[28] See Burniaux et al. 1992.

[29] For example, if energy is priced at $50 per ton of oil equivalent and the average carbon content is 50% and the substitution elasticity is 0.8 and a carbon tax of $150 per ton of carbon is imposed, the level of reduction would be 52 percent.

Table 1a: Regional dimensions of ENVISAGE[a]

1	eur	EU27 with EFTA Austria (aut), Belgium (bel), Cyprus (cyp), Czech Republic (cze), Denmark (dnk), Estonia (est), Finland (fin), France (fra), Germany (deu), Greece (grc), Hungary (hun), Ireland (irl), Italy (ita), Latvia (lva), Lithuania (ltu), Luxembourg (lux), Malta (mlt), Netherlands (nld), Poland (pol), Portugal (prt), Slovakia (svk), Slovenia (svn), Spain (esp), Sweden (swe), United Kingdom (gbr), Switzerland (che), Norway (nor), Rest of EFTA (xef), Bulgaria (bgr), Romania (rou)
2	usa	United States
3	jpn	Japan
4	kor	Korea
5	rha	Rest of high income Annex 1 Australia (aus), New Zealand (nzl), Canada (can)
6	rhy	Rest of high income Hong Kong (hkg), Taiwan (twn), Singapore (sgp)
6	bra	Brazil
7	chn	China
8	ind	India
9	rus	Russia
10	xea	Rest of East Asia Rest of Oceania (xoc), Rest of East Asia (xea), Cambodia (khm), Laos (lao), Myanmar (mmr), Viet Nam (vnm), Indonesia (idn), Malaysia (mys), Philippines (phl), Thailand (tha), Bangladesh (bgd), Pakistan (pak)
11	xsa	Rest of South Asia Rest of Southeast Asia (xse), Sri Lanka (lka), Rest of South Asia (xsa)
12	xec	Rest of Europe and Central Asia Albania (alb), Belarus (blr), Croatia (hrv), Ukraine (ukr), Rest of Eastern Europe (xee), Rest of Europe (xer), Kazakhstan (kaz), Kyrgystan (kgz), Rest of Former Soviet Union (xsu), Armenia (arm), Azerbaijan (aze), Georgia (geo)
13	mna	Middle East and North Africa Iran (irn), Turkey (tur), Rest of Western Asia (xws), Egypt (egy), Morocco (mar), Tunisia (tun), Rest of North Africa (xnf)
14	ssa	Sub-Saharan Africa Nigeria (nga), Senegal (sen), Rest of Western Africa (xwf), Central Africa (xcf), South-Central Africa (xac), Ethiopia (eth), Madagascar (mdg), Malawi (mwi), Mauritius (mus), Mozambique (moz), Tanzania (tza), Uganda (uga), Zambia (zmb), Zimbabwe (zwe), Rest of Eastern Africa (xec), Botswana (bwa), South Africa (zaf), Rest of South African Customs Union (xsc)
15	xlc	Rest of Latin America and the Caribbean Mexico (mex), Rest of North America (xna), Argentina (arg), Bolivia (bol), Chile (chl), Colombia (col), Ecuador (ecu), Paraguay (pry), Peru (per), Uruguay (ury), Venezuela (ven), Rest of South America (xsm), Costa Rica (cri), Guatemala (gtm), Nicaragua (nic), Panama (pan), Rest of Central America (xca), Caribbean (xcb)
Note(s):		a) Aggregate regions indicate relevant GTAP countries/regions with GTAP code in parenthesis.

Appendix Table 1b: Sectoral dimensions of ENVISAGE[a]

1	cop	Crops Paddy rice (pdr), Wheat (wht), Cereal grains, n.e.s. (gro), Vegetables and fruits (v_f), Oil seeds (osd), Sugar cane and sugar beet (c_b), Plant-based fibers (pfb), Crops, n.e.s. (ocr)
2	lvs	Livestock Bovine cattle, sheep and goats, horses (ctl), Animal products n.e.s. (oap), Raw milk (rmk), Wool, silk-worm cocoons (wol)
3	frs	Forestry
4	coa	Coal
5	oil	Crude oil
6	gas	Natural gas
7	omn	Other mining
8	pfd	Processed food Fishing (fsh), Bovine cattle, sheep and goat, horse meat products (cmt), Meat products n.e.s. (omt), Vegetable oils and fats (vol), Dairy products (mil), Processed rice (pcr), Sugar (sgr), Food products n.e.s. (ofd), Beverages and tobacco products (b_t)
9	p_c	Refined oil
10	crp	Chemicals rubber and plastics
11	ppp	Paper products, publishing
12	nmm	Mineral products n.e.s.
13	i_s	Ferrous metals
14	nfm	Metals n.e.s.
15	tre	Transport equipment Motor vehicles and parts (mvh), Transport equipment n.e.s. (otn)
16	mnu	Other manufacturing Textiles (tex), Wearing apparel (wap), Leather products (lea), Wood products (lum), Metal products (fmp), Electronic equipment (ele), Machinery and equipment n.e.s. (ome), Manufactures n.e.s. (omf)
17	ely	Electricity[b]
18	gdt	Gas distribution
19	cns	Construction
20	trp	Transport services Transport n.e.s. (otp), Sea transport (wtp), Air transport (atp)
21	osv	Other services Water (wtr), Trade (trd), Communication (cmn), Financial services n.e.s. (ofi), Insurance (isr), Business services n.e.s. (obs), Recreation and other services (ros), Public administration and defence, education, health services (osg), Dwellings (dwe)

Note(s): a) Aggregate sectors indicate relevant GTAP sectors with GTAP code in parenthesis.
b) Electricity is a single consumed and traded commodity. However, in each region/country it is produced by multiple activities that include coal and gas power plants, hydro-electricity, nuclear and other (mainly renewable) technologies.

Appendix Table 2. Emissions Reductions (percent)

	EU27 with EFTA	United States	Japan	Rest of high income Annex 1	Rest of high income	Brazil	China	India	Russia	Rest of East Asia	Rest of South Asia	Rest of ECA	Middle East and North Africa	Sub-Saharan Africa	Rest of LAC	High income countries	Low and middle income countries	World total
Relative to Business as Usual (BAU) in 2020																		
NTER	-40.9	-43.9	-29.0	-44.7	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-30.0	-40.9	-30.0	-33.8
TER1	-14.8	-21.4	-8.9	-24.5	-21.6	-14.9	-50.5	-38.0	-47.9	-24.5	-32.0	-36.6	-29.7	-42.3	-24.1	-18.8	-41.9	-33.8
TER	-15.0	-21.5	-8.9	-24.6	-21.8	-15.0	-50.4	-38.0	-47.2	-24.7	-32.1	-36.5	-29.9	-42.3	-24.2	-19.0	-41.8	-33.8
TERWMT	-15.5	-21.8	-9.3	-24.7	-21.9	-15.0	-50.4	-37.9	-46.7	-24.3	-31.8	-36.3	-29.6	-42.0	-23.6	-19.4	-41.6	-33.8
Relative to 2005																		
NTER	-30.0	-30.0	-30.0	-30.0	19.9	-5.0	97.3	78.0	56.8	20.1	53.4	55.4	-6.9	24.0	19.4	-26.9	54.3	14.5
TER1	1.1	-1.9	-10.1	-4.4	34.2	15.6	39.6	57.6	16.8	29.6	48.9	40.8	-6.6	2.2	29.5	0.4	28.0	14.5
TER	0.8	-2.1	-10.2	-4.6	34.0	15.4	39.9	57.7	18.2	29.2	48.7	41.1	-6.8	2.3	29.3	0.2	28.2	14.5
TERWMT	0.1	-2.4	-10.5	-4.8	33.8	15.4	39.8	58.0	19.5	29.9	49.5	41.5	-6.3	2.8	30.2	-0.2	28.6	14.5

*Notes: **NTER:** Both industrial and developing countries reduce emissions but emissions rights are not tradeable; **TER1:** Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers; **TER:** Both industrial and developing countries reduce emissions and emissions rights are tradeable; **TERWMT:** Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions*

Appendix Table 3. Emissions Tax in dollars per ton carbon

	EU27 with EFTA	United States	Japan	Rest of high income Annex 1	Rest of high income	Brazil	China	India	Russia	Rest of East Asia	Rest of South Asia	Rest of ECA	Middle East and North Africa	Sub-Saharan Africa	Rest of LAC	High income countries	Low and middle income countries	World total
NTER	634.8	418.2	638.1	388.9	217.1	375.9	54.4	92.4	55.4	190.5	122.7	100.1	139.4	75.9	192.3	477.6	91.9	212.4
TER1	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7	131.7
TER	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7	132.7
TERWMT	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3	134.3

*Notes: Changes are expressed relative to business-as-usual in 2020; **NTER:** Both industrial and developing countries reduce emissions but emissions rights are not tradeable; **TER1:** Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers; **TER:** Both industrial and developing countries reduce emissions and emissions rights are tradeable; **TERWMT:** Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions*

Appendix Table 4. Change in Welfare by regions (percent)

Scenarios → / ↓ Countries/Regions	Cooperative Reductions			
	NTER	TER1	TER	TERWMT
EU27 with EFTA	-1.3	-0.1	-0.4	-1.4
United States	-1.3	-0.2	-0.7	-1.1
Japan	-0.6	0.0	-0.2	-0.9
Rest of high income Annex 1	-1.9	-0.7	-1.1	-1.7
Rest of high income	-0.7	-0.3	-0.5	0.0
Brazil	-1.4	-0.5	-0.8	0.0
China	-1.8	-3.8	-1.5	0.0
India	-1.5	-2.1	-1.5	0.0
Russia	-3.6	-4.3	-2.1	0.0
Rest of East Asia	-2.6	-1.7	-2.0	0.0
Rest of South Asia	-2.2	-2.0	-1.9	0.0
Rest of ECA	-2.0	-2.5	-1.5	0.0
Middle East and North Africa	-2.5	-2.1	-2.1	0.0
Sub-Saharan Africa	-1.9	-2.0	-1.5	0.0
Rest of LAC	-3.2	-2.0	-2.2	0.0
High income countries	-1.2	-0.2	-0.5	-1.2
Low and middle income countries	-2.2	-2.6	-1.7	0.0
World total	-1.5	-0.9	-0.9	-0.8

Notes: Changes are expressed relative to business-as-usual in 2020; ***NTER:*** *Both industrial and developing countries reduce emissions but emissions rights are not tradeable;* ***TER1:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers;* ***TER:*** *Both industrial and developing countries reduce emissions and emissions rights are tradeable;* ***TERWMT:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions*

Appendix Table 5. Change in Output by sector (percent)

	EU27 with EFTA	United States	Japan	Rest of high income Annex 1	Rest of high income	Brazil	China	India	Russia	Rest of East Asia	Rest of South Asia	Rest of ECA	Middle East and North Africa	Sub-Saharan Africa	Rest of LAC	High income countries	Low and middle income countries	World total
NTER																		
Agriculture	-2.2	-4.2	-1.1	-1.3	-0.5	-2.9	0.9	-0.2	1.5	1.0	0.8	-0.5	0.9	0.5	0.6	-2.7	0.4	-0.9
All energy	-8.9	-17.7	-3.1	-13.7	-2.2	-10.0	-9.3	-10.8	-7.9	-13.1	-15.5	-7.2	-11.1	-7.0	-20.4	-11.6	-11.2	-11.4
All manufacturing	-0.7	-1.3	-1.6	0.5	-2.1	-0.8	-2.9	-3.7	1.5	-1.4	-4.0	-4.0	-5.9	1.8	0.2	-1.1	-2.5	-1.7
Energy intensive manufacturing	-0.2	-4.4	-2.2	-4.1	-0.2	-3.0	-1.8	-4.5	5.4	-3.9	-20.0	-7.1	-12.9	6.2	-0.4	-1.8	-2.7	-2.2
Other manufacturing	-1.0	0.1	-1.2	3.5	-2.9	0.2	-3.6	-3.3	-0.8	-0.6	0.0	-2.2	-3.5	-0.3	0.4	-0.7	-2.4	-1.4
Other industries	-0.6	-1.8	-0.6	-3.7	0.1	-1.0	-1.9	-1.7	-1.7	-2.0	-2.3	-2.5	-1.5	-1.7	-2.1	-1.1	-1.8	-1.4
Service	-0.9	-0.6	-0.1	-1.1	0.0	-1.1	-1.3	-1.3	-1.0	-1.3	0.3	-1.2	0.2	-0.3	-1.8	-0.7	-1.0	-0.7
Total	-1.1	-1.6	-0.6	-1.8	-1.0	-1.9	-2.7	-3.0	-1.9	-2.5	-2.6	-3.3	-2.8	-0.4	-3.2	-1.3	-2.6	-1.7
TER1																		
Agriculture	-1.8	-4.1	-1.0	-4.1	-0.8	-3.3	1.3	-0.3	2.3	0.4	0.9	-0.4	0.6	0.9	0.0	-2.7	0.4	-1.0
All energy	-3.5	-10.2	-0.6	-7.8	-2.6	-4.9	-15.6	-14.6	-13.2	-10.4	-16.1	-10.0	-12.0	-7.8	-15.3	-6.1	-13.2	-10.0
All manufacturing	0.5	0.0	-0.2	1.5	-0.6	0.6	-5.8	-5.2	-4.7	-0.4	-3.5	-4.6	-4.5	0.9	0.2	0.2	-4.0	-1.6
Energy intensive manufacturing	2.8	-0.1	2.3	1.1	2.3	0.8	-9.3	-9.4	-9.4	-2.1	-22.5	-13.8	-13.4	1.5	-1.2	1.8	-7.8	-2.1
Other manufacturing	-0.7	0.0	-1.4	1.7	-2.0	0.4	-4.1	-3.1	-2.0	0.1	1.1	0.6	-1.5	0.6	0.8	-0.6	-2.2	-1.3
Other industries	-0.1	-0.8	0.0	-1.4	0.4	-0.4	-4.4	-2.8	-1.8	-1.7	-2.2	-3.5	-1.3	-2.3	-1.4	-0.3	-3.0	-1.5
Service	-0.3	-0.2	0.0	-0.5	-0.2	-0.5	-3.1	-1.8	-0.9	-1.1	0.1	-1.9	0.0	-0.6	-1.4	-0.2	-1.6	-0.5
Total	-0.1	-0.7	-0.1	-0.7	-0.5	-0.7	-5.3	-4.2	-4.5	-1.7	-2.6	-4.4	-2.5	-1.0	-2.4	-0.4	-3.7	-1.5
TER																		
Agriculture	-1.6	-2.8	-1.0	-2.7	-0.8	-2.5	1.3	-0.3	2.3	0.4	0.9	-0.1	0.6	0.9	0.1	-2.0	0.5	-0.6
All energy	-3.5	-10.1	-0.5	-7.5	-2.5	-4.8	-15.2	-14.5	-13.2	-10.4	-16.1	-9.9	-12.0	-7.7	-15.1	-6.0	-13.0	-9.9
All manufacturing	0.7	0.8	0.1	1.9	-0.4	0.6	-6.5	-5.5	-5.7	-0.3	-3.6	-5.0	-4.6	0.7	0.1	0.6	-4.4	-1.5
Energy intensive manufacturing	3.0	0.7	2.6	1.6	2.5	0.9	-9.7	-9.7	-11.1	-2.1	-22.6	-14.5	-13.6	1.2	-1.3	2.2	-8.1	-2.1
Other manufacturing	-0.4	0.9	-1.1	2.1	-1.7	0.4	-4.9	-3.3	-2.6	0.2	1.0	0.4	-1.5	0.5	0.8	-0.2	-2.7	-1.2
Other industries	-0.4	-1.1	-0.2	-1.5	0.2	-0.6	-2.2	-2.2	-0.1	-1.8	-2.1	-2.8	-1.4	-1.8	-1.5	-0.6	-1.9	-1.1
Service	-0.3	-0.3	-0.1	-0.7	-0.3	-0.6	-2.1	-1.6	0.1	-1.3	0.1	-1.6	-0.1	-0.5	-1.4	-0.3	-1.2	-0.5
Total	-0.1	-0.5	-0.1	-0.6	-0.4	-0.7	-5.1	-4.2	-4.1	-1.7	-2.6	-4.3	-2.5	-0.9	-2.4	-0.3	-3.6	-1.4
TERWMT																		
Agriculture	-0.9	-1.3	-0.7	-0.6	-0.8	-2.6	1.3	0.0	2.4	0.4	0.9	0.4	0.9	0.8	-0.4	-1.0	0.5	-0.1
All energy	-3.4	-10.0	-0.5	-7.0	-2.6	-5.0	-14.9	-14.2	-13.1	-9.8	-15.9	-9.6	-11.5	-7.3	-15.5	-5.9	-12.8	-9.7
All manufacturing	1.3	1.6	1.4	2.5	-0.6	-0.2	-7.0	-6.1	-6.9	-1.0	-5.2	-5.8	-4.9	0.3	-0.7	1.2	-5.0	-1.4
Energy intensive manufacturing	3.6	1.3	3.8	2.3	2.2	-0.1	-10.0	-10.6	-13.2	-2.9	-23.1	-15.5	-14.0	0.5	-1.8	2.8	-8.7	-1.9
Other manufacturing	0.1	1.7	0.2	2.7	-1.9	-0.2	-5.5	-3.9	-3.4	-0.4	-0.7	-0.2	-1.8	0.2	-0.1	0.5	-3.3	-1.1
Other industries	-1.1	-1.4	-0.9	-1.7	0.7	0.3	-0.8	-1.0	1.5	0.1	-0.3	-1.8	0.8	-0.6	0.4	-1.0	-0.4	-0.7
Service	-0.6	-0.5	-0.4	-0.9	-0.3	-0.4	-1.5	-1.1	1.1	-0.5	0.7	-1.1	0.5	0.0	-0.5	-0.5	-0.6	-0.5
Total	-0.1	-0.5	0.1	-0.6	-0.4	-0.8	-5.0	-4.1	-3.8	-1.5	-2.7	-4.2	-2.2	-0.6	-2.4	-0.2	-3.5	-1.3

Notes: Changes are expressed relative to business-as-usual in 2020; ***NTER:*** *Both industrial and developing countries reduce emissions but emissions rights are not tradeable;* ***TER1:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers;* ***TER:*** *Both industrial and developing countries reduce emissions and emissions rights are tradeable;* ***TERWMT:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions*

Appendix Table 6. Change in Exports by sector (percent)

	EU27 with EFTA	United States	Japan	Rest of high income Annex 1	Rest of high income	Brazil	China	India	Russia	Rest of East Asia	Rest of South Asia	Rest of ECA	Middle East and North Africa	Sub-Saharan Africa	Rest of LAC	High income countries	Low and middle income countries	World total
NTER																		
Agriculture	-14.4	-8.2	-13.2	-3.1	-9.4	-7.5	4.8	5.4	13.2	-0.7	-0.9	-4.1	0.8	1.2	0.2	-8.0	-3.2	-6.8
All energy	-14.0	-36.6	-5.4	-18.7	14.7	-4.7	-13.1	7.3	-11.7	-7.9	-6.8	-8.3	-21.3	-7.8	-23.4	-20.2	-13.7	-15.2
All manufacturing	-1.9	-2.3	-3.9	0.5	-3.3	-1.5	-4.5	-7.3	8.1	-1.7	-5.6	-5.7	-8.4	5.8	6.3	-2.4	-3.5	-2.9
Energy intensive manufacturing	1.7	-10.7	-6.2	-8.5	-0.3	-9.5	1.8	-6.8	14.3	-4.5	-43.4	-7.9	-19.1	15.3	8.4	-4.2	-2.7	-3.5
Other manufacturing	-3.7	1.1	-3.3	6.7	-4.1	2.2	-5.6	-7.5	-0.4	-1.0	-0.1	-4.0	-5.4	-1.3	5.5	-1.7	-3.7	-2.7
Other industries	-5.0	-1.7	-3.1	-15.8	-6.5	-8.5	-2.2	-3.1	3.1	1.3	2.0	-7.2	1.3	-1.1	6.8	-7.5	0.1	-3.0
Service	-5.4	-4.2	-0.6	0.3	0.7	-11.0	7.3	6.8	17.1	-1.9	13.1	8.3	5.7	4.8	-0.3	-3.5	5.2	-0.1
Total	-3.7	-4.5	-3.6	-3.3	-2.5	-4.4	-3.8	-4.0	-3.2	-2.4	-2.1	-4.5	-4.1	-0.7	-5.1	-3.6	-3.7	-3.6
TER1																		
Agriculture	-13.2	-8.4	-15.2	-7.2	-10.5	-8.6	23.8	9.5	19.0	-3.2	-1.7	-4.8	0.5	3.2	-1.7	-8.9	-4.0	-7.7
All energy	-2.3	-19.3	4.1	-10.8	5.6	-8.3	-15.4	-0.3	-1.3	-6.1	-2.6	-7.2	-12.7	-5.2	-15.2	-9.4	-8.3	-8.5
All manufacturing	1.2	0.1	-0.8	2.5	-1.3	2.0	-5.8	-8.6	-9.6	-0.2	-3.4	-6.3	-5.8	3.5	5.2	0.2	-3.9	-1.8
Energy intensive manufacturing	10.9	0.4	10.6	1.5	4.4	3.3	-21.8	-20.3	-15.0	-2.0	-48.5	-17.0	-20.1	4.0	3.9	5.6	-13.4	-2.4
Other manufacturing	-3.4	0.0	-4.0	3.3	-2.9	1.5	-2.9	-4.3	-2.1	0.3	3.2	1.6	-1.7	3.2	5.7	-2.0	-1.2	-1.6
Other industries	-5.1	-3.0	-3.6	-7.2	-6.3	-3.0	-3.1	-8.4	2.3	-4.6	1.0	-9.5	0.3	-5.5	3.4	-5.3	-2.6	-3.7
Service	-3.9	-2.9	-2.7	0.0	-1.0	-5.4	8.1	11.6	5.7	-3.3	8.6	4.8	3.6	1.5	-3.7	-2.8	3.8	-0.3
Total	-0.8	-2.0	-1.0	-1.1	-1.2	-2.7	-5.0	-4.5	-3.4	-1.3	-0.9	-5.2	-2.9	-1.1	-3.1	-1.3	-3.5	-2.4
TER																		
Agriculture	-10.4	-5.7	-13.0	-4.8	-8.6	-6.5	14.5	5.1	6.4	-1.0	-0.1	-5.3	2.1	2.1	0.3	-6.2	-2.5	-5.4
All energy	-2.4	-17.8	4.8	-10.1	6.5	-6.8	-17.6	-0.5	-4.0	-5.8	-2.2	-7.5	-12.4	-5.1	-14.6	-8.7	-8.7	-8.7
All manufacturing	2.6	2.7	0.0	3.6	-0.9	2.7	-9.4	-10.7	-14.7	0.1	-3.8	-7.2	-5.9	2.3	5.5	1.6	-5.6	-1.9
Energy intensive manufacturing	12.0	2.6	11.5	2.7	4.8	3.7	-24.7	-21.6	-19.4	-2.0	-48.9	-18.0	-20.3	3.1	4.2	6.9	-14.7	-2.2
Other manufacturing	-1.9	2.7	-3.2	4.3	-2.5	2.3	-6.6	-6.7	-8.3	0.6	2.7	0.8	-1.8	1.8	6.0	-0.5	-3.0	-1.8
Other industries	-3.9	-0.7	-2.6	-5.7	-5.3	-1.6	-5.5	-8.6	-0.8	-2.6	1.3	-10.2	0.7	-5.5	4.3	-3.8	-2.5	-3.0
Service	-3.4	-1.3	-2.6	0.7	-1.1	-5.1	4.6	9.3	1.1	-3.7	7.9	3.1	3.6	0.2	-3.5	-2.1	2.7	-0.3
Total	0.3	0.3	-0.2	0.0	-0.9	-1.5	-8.6	-6.5	-7.0	-1.0	-1.3	-6.0	-3.0	-1.6	-2.7	0.0	-4.9	-2.3
TERWMT																		
Agriculture	-4.1	-2.7	-6.9	-1.5	-7.3	-6.7	11.5	-2.8	-2.9	-2.6	-1.4	-5.6	-0.4	-1.5	-4.0	-2.7	-4.4	-3.1
All energy	-0.7	-16.4	6.0	-8.7	7.0	-7.6	-17.8	-0.9	-6.0	-5.3	-3.3	-7.3	-12.7	-4.6	-15.9	-7.3	-9.4	-8.9
All manufacturing	6.5	5.0	4.4	5.1	-1.2	-0.7	-11.7	-15.4	-20.0	-1.7	-8.8	-8.8	-7.7	-1.0	0.3	3.9	-8.3	-1.9
Energy intensive manufacturing	15.6	4.8	15.8	4.1	4.4	0.3	-26.6	-24.6	-24.1	-3.8	-51.0	-19.5	-21.7	0.4	-0.6	9.2	-17.1	-1.9
Other manufacturing	2.2	5.2	1.2	5.7	-2.8	-1.1	-9.0	-12.0	-14.4	-1.2	-2.7	-1.0	-3.8	-2.0	0.6	1.9	-5.7	-1.9
Other industries	-1.1	1.8	0.2	-3.5	-4.6	-3.2	-6.4	-10.0	-4.2	-2.2	-0.4	-11.0	0.0	-6.6	1.4	-1.3	-3.7	-2.7
Service	-1.0	0.0	-0.2	1.8	-1.8	-8.4	2.3	4.6	-3.6	-5.7	3.2	1.1	1.3	-2.8	-8.1	-0.6	-0.1	-0.4
Total	3.8	2.6	3.9	1.7	-1.2	-3.6	-10.8	-10.8	-10.2	-2.5	-5.6	-7.3	-4.9	-3.2	-6.4	2.2	-7.2	-2.3

Notes: Changes are expressed relative to business-as-usual in 2020; ***NTER:*** *Both industrial and developing countries reduce emissions but emissions rights are not tradeable;* ***TER1:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; but we abstract from private transfers;* ***TER:*** *Both industrial and developing countries reduce emissions and emissions rights are tradeable;* ***TERWMT:*** *Both industrial and developing countries reduce emissions; emissions rights are tradeable; and transfers offset welfare loss from emissions*

Appendix Table 7. Carbon Intensity by sector (in tons per million US dollars, 2004)

	EU27 with EFTA	United States	Japan	Rest of high income Annex 1	Rest of high income	Brazil	China	India	Russia	Rest of East Asia	Rest of South Asia	Rest of ECA	Middle East and North Africa	Sub-Saharan Africa	Rest of LAC	High income countries	Low and middle income countries	World total
Direct Intensity																		
Agriculture	40	57	41	45	39	63	82	0	65	24	9	94	44	15	46	45	47	46
All energy	485	879	396	611	609	116	2067	1501	984	665	678	785	456	727	458	642	886	758
All manufacturing	18	36	21	38	36	53	127	111	158	91	127	243	152	65	47	25	107	46
Energy intensive manufacturing	43	90	53	92	98	141	326	283	313	288	735	538	384	159	126	62	279	116
Other manufacturing	7	12	6	8	8	8	35	36	31	34	20	74	50	17	13	8	31	14
Other industries	6	3	6	34	5	18	29	13	30	38	4	62	36	38	25	7	30	13
Service	21	32	16	38	39	63	82	68	171	135	89	213	107	67	73	26	97	36
Total	40	74	34	81	80	78	303	250	385	195	167	383	228	149	114	55	228	92
Total (Direct plus Indirect) Intensity																		
Agriculture	74	141	76	126	112	129	350	301	307	75	104	335	184	72	113	98	223	168
All energy	541	1016	433	735	636	186	2800	1749	1333	752	753	982	582	823	609	729	1147	928
All manufacturing	62	159	79	156	133	168	681	518	848	244	282	712	378	273	144	99	449	187
Energy intensive manufacturing	107	272	140	293	251	286	1163	888	1193	541	1062	1190	746	505	264	172	811	330
Other manufacturing	42	111	51	81	80	107	459	354	568	158	145	437	215	156	92	66	289	122
Other industries	46	69	46	114	77	89	561	287	381	232	218	401	179	240	110	60	342	132
Service	46	94	40	89	100	101	340	231	409	265	160	435	232	161	133	67	242	92
Total	74	153	70	157	155	149	772	535	767	332	281	672	380	281	199	109	479	187

Appendix Table 8. Share of Output by sector (% of total output, 2004)

	EU27 with EFTA	United States	Japan	Rest of high income Annex 1	Rest of high income	Brazil	China	India	Russia	Rest of East Asia	Rest of South Asia	Rest of ECA	Middle East and North Africa	Sub-Saharan Africa	Rest of LAC
Agriculture	1.7	1.2	1.1	2.1	1.3	6.2	6.2	13.2	4.3	5.2	14.8	8.9	5.9	8.9	5.3
All energy	3.1	4.0	2.7	5.8	5.2	8.3	7.1	9.8	24.1	9.5	7.7	22.2	23.4	10.6	9.3
All manufacturing	35.3	23.9	31.8	25.9	42.2	33.9	49.8	35.4	23.8	47.5	31.5	24.4	24.3	29.3	41.3
Energy intensive manufacturing	11.1	7.2	10.0	9.2	13.0	11.5	15.7	10.9	10.7	10.7	4.7	8.9	7.4	9.8	12.6
Other manufacturing	24.3	16.8	21.8	16.7	29.1	22.3	34.1	24.5	13.1	36.8	26.8	15.5	16.9	19.5	28.7
Other industries	5.9	7.0	7.5	8.8	6.5	8.9	10.9	8.5	8.5	7.1	8.4	9.0	7.7	7.5	5.4
Service	53.9	63.9	56.9	57.3	44.9	42.8	26.0	33.1	39.3	30.7	37.6	35.5	38.7	43.6	38.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix Table 9. Share of Exports by sector (% of total exports, 2005)

	EU27 with EFTA	United States	Japan	Rest of high income Annex 1	Rest of high income	Brazil	China	India	Russia	Rest of East Asia	Rest of South Asia	Rest of ECA	Middle East and North Africa	Sub-Saharan Africa	Rest of LAC
Agriculture	0.8	3.7	0.1	4.1	0.1	10.4	1.1	3.7	0.6	1.7	3.4	4.3	1.9	7.9	6.2
All energy	2.5	2.2	0.3	10.0	2.3	4.3	2.0	3.6	52.9	7.1	9.7	24.7	49.4	34.6	17.8
All manufacturing	69.4	69.5	90.3	66.6	77.3	68.5	89.9	69.7	36.0	79.6	70.5	53.0	32.6	37.7	61.4
Energy intensive manufacturing	20.6	19.0	17.5	21.6	16.9	20.6	12.0	19.3	25.4	14.0	4.6	25.7	11.4	17.4	15.0
Other manufacturing	48.8	50.5	72.8	45.1	60.5	47.8	78.0	50.4	10.5	65.6	65.9	27.2	21.2	20.3	46.4
Other industries	1.8	0.9	1.1	3.6	0.2	7.2	0.6	5.0	3.4	1.6	0.7	2.8	1.8	7.4	3.1
Service	25.5	23.8	8.3	15.6	20.0	9.6	6.4	18.0	7.2	10.1	15.8	15.2	14.3	12.5	11.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0