Number 6/2005/p.95-104 www.CAFRI.org

Current Agriculture, Food & Resource Issues

A Journal of the Canadian Agricultural Economics Society

Will the Kyoto Protocol Be Good for the Environment? Implications for Agriculture[1]

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This paper was presented at the annual meeting of the Canadian Agricultural Economics Society (Montreal, July 2003) in a session entitled "Ramifications of Multilateral Environmental Agreements for the Agri-food Sector". Papers presented at CAES meetings are not subject to the journal's standard refereeing process.

The Issue

Global warming or, more accurately, climate change remains a hotly debated issue in scientific, government and public circles. While the extent of the human contribution to climate change through greenhouse gas (GHG) emissions remains highly controversial, the scientific evidence of significant changes in climate per se appears to be mounting (Intergovernmental Panel on Climate Change, 2001). Since changes in climate typically will include greater variability in temperatures, more extreme weather events and changes in precipitation patterns as well as a general warming trend, there are significant risks for agriculture.[2] If human activity does turn out to have a significant causal effect on climate change, the Kyoto Protocol and other related multilateral environmental agreements appear to have the potential to reduce these risks. The Kyoto Protocol, however, leaves possible channels for *increases* in emissions or so-called *carbon leakage*.

Implications and Conclusions

This article examines the possibility of global carbon leakage and finds that the Kyoto agreement might be counterproductive in the sense that compliance by signatory countries could lead to an increase in global GHG emissions. The article reports on a larger project (Pancoast, 2003) and extends the analysis to deal explicitly with agricultural issues. The method follows Copeland and Taylor (1994, 1995, 2005), Antweiler et al. (2001) and others in applying general equilibrium modeling to explore both environmental and international trade linkages between countries. The article demonstrates three important results. First, declining agricultural productivity resulting from climate change may lead to increases rather than decreases in global emissions and, thus, accelerate rather than decelerate the pace of climate change. Second, the exemption of developing countries from emission caps under the Kyoto agreement will not only tend to generate carbon leakage at the national level as these countries emit more, but will also tend to generate carbon leakage at the global level because the increases in emissions by the unconstrained developing countries will tend to exceed the reductions by the developed countries. Third, the clean development mechanism in the Kyoto agreement, which allows firms in developing countries to reduce emissions and sell corresponding credits to firms in developed countries, *may* cause further global carbon leakage. To provide a foundation for these results, we construct a simple two-country, two-good, general-equilibrium trade model.

Overview of the Model

North is a developed country while South is a developing country. Each country has a two-sector economy that is diversified in the sense that it produces both a manufactured good and an agricultural good. Manufacturing is modeled as a *dirty sector* where emissions occur, while agriculture is assumed to be a *clean sector* for simplicity. Labour is the only conventional input and it is perfectly mobile between sectors within countries, but internationally immobile.[3] For convenience, the level of emissions in manufacturing is treated as an additional input, which is specific to manufacturing (see Copeland and Taylor, 2005). Both sectors are assumed to be competitive. Further, we take a long-run perspective where maximum profits are equal to zero. In each sector, the equilibrium price is equal to the firms' minimum long-run average cost. The agricultural good is chosen as the numeraire (i.e., its price is always set equal to one) and we focus on the price of the manufactured good measured relative to the agricultural good.

Manufacturing output depends on the level of emissions as well as the labour input. The minimum average cost, thus, depends on the price charged per unit of emissions as well as the wage paid per unit of labour. In figure 1, the break-even curves for manufacturing in North and South, BEM_N and BEM_S respectively, depict the zero-profit equilibrium conditions for the sector where the price is equal to the minimum average cost. The negative slopes of these curves arise because an increase in the price of emissions would necessitate a reduction in the wage if the zero-profit equilibrium were to be maintained. For simplicity, we will assume that the technology is such that the minimum efficient scale of output that results in minimum average cost is invariant to changes in the ratio of emissions to labour and, thus, to changes in the wage and price of

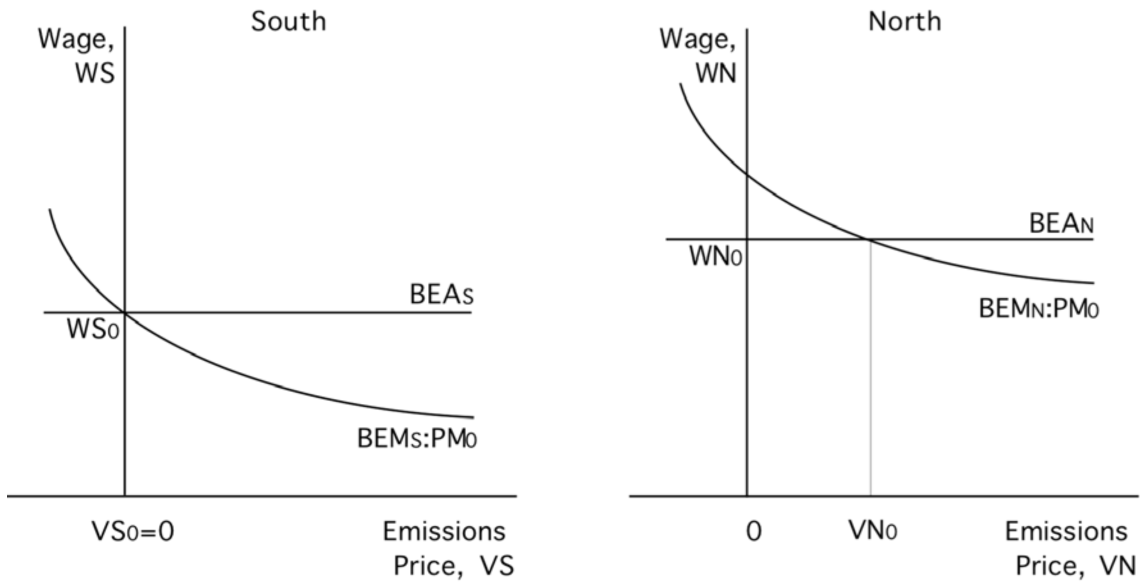

Figure 1 Zero-profit equilibrium prices

emissions. Further, we assume that technological differences between North and South are such that emissions per unit of output are greater in South than North in the initial equilibrium.

The flow of emissions from the manufacturing sector affects the world economy via several channels. To begin with, emissions cause local air pollution, which acts as a negative national externality that adversely affects national welfare in the polluting country.[4] Due to its higher per capita income, it is assumed that North initially has a binding cap on aggregate emissions whereas South does not have a binding emissions cap.[5] The flow of emissions from manufacturing also increases the stock of GHGs in the atmosphere, which contributes to global climate change. Climate change has a negative external effect that directly reduces welfare in both countries. As we will see, climate change also has adverse indirect effects on national welfare in both countries through diminished productivity in agriculture.

By contrast with manufacturing, agriculture is modeled as a clean sector that does not cause emissions. While this may be an overstatement given the sector's reliance on fuel and other emitting inputs, in reality agriculture also plays an important role in combating climate change. Agriculture has the ability to *sequester* carbon dioxide and by so doing it removes a key GHG from the atmosphere and deposits it for storage in soils.[6] For simplicity, we assume the sector does not have any *net* emissions. Regardless, the key results of the model carry over to the case where there are emissions from agriculture but manufacturing is more emissions intensive than agriculture. Climate change is assumed to have a negative external effect on labour productivity in agriculture in both North and South. The break-even curves for agriculture in North and South, BEA_N and BEA_S

respectively in figure 1, show the zero-profit equilibrium for the sector conditional on the prevailing climate conditions. These curves are independent of the price of emissions because agriculture has been assumed to be a non-emitting sector.

When both countries are diversified in the sense that each produces some of both goods, there is a simple recursive or sequential method of determining equilibrium in the model. Since the agricultural good is the numeraire, the positions of the break-even curves for agriculture in both North and South, BEA_N and BEA_S in figure 1, are determined by labour productivity alone. Because these curves are independent of emissions prices, the wages in North and South, WN_0 and WS_0 respectively, are determined at once. Given that North's labour productivity in agriculture exceeds that of South, North's wage must exceed that of South. In South, where there is no cap or tax on emissions, the price of emissions is equal to zero in equilibrium. There is a unique price of the manufactured good measured relative to the agricultural good, say PM_0, where South's break-even curve for the manufacturing sector, $BEM_S{:}PM_0$, passes through the point where the emissions price is $VS_0 = 0$ and the wage is WS_0. This allows manufacturing as well as agriculture to attain a zero-profit long-run equilibrium.[7] Meanwhile, in North, the positions of the break-even curves for both agriculture and manufacturing are established by the prevailing product prices, $PA = 1$ and PM_0. Accordingly, the Northern wage is WN_0 and the Northern emissions price is VN_0. Consequently, emission permits trade at the price of VN_0 given the aggregate emissions cap initially in place in North.

The goods markets subsequently determine the quantities produced and consumed in each country since the product prices consistent with diversified production in both countries have already been determined. If the goods market in the manufacturing sector is in equilibrium, a foundational tenet of general equilibrium analysis known as Walras' Law implies that the agricultural sector is in equilibrium as well (Gravelle and Rees, 2004, ch. 12). Consequently, in what follows we can focus on the international equilibrium in the manufacturing sector. Figure 2 shows that North's supply curve for the manufactured good, S_N, is positively sloped. Due to the emissions cap, the manufacturing sector in North faces increasing costs. In the course of increasing its manufacturing output, the North's price of emissions is bid up and the long-run minimum average cost increases. This requires a higher price for the manufactured good if the North's manufacturing firms are to earn zero profit at the higher output. By contrast, South is able to supply the manufactured good perfectly elastically at a price of PM_0, because it is not constrained by an emissions cap. As entry leads to additional manufacturing output in South, its emissions simply rise in proportion to output. If we say that xs^o represents the underlying profit-maximizing emissions level per Southern firm where the value of the marginal product of emissions is equal to zero, then each new entrant increases South's emissions by exactly xs^o. Given that D is the world demand curve for the manufactured good in figure 2, the equilibrium output of the manufactured good in North is MN_0 and

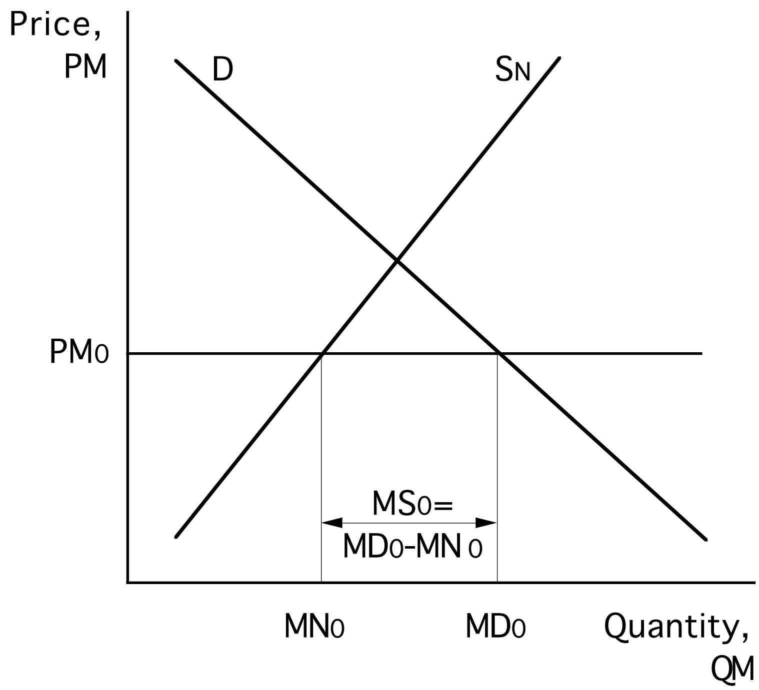

Figure 2 Goods-market equilibrium in manufacturing

world consumption is MD_0. Southern manufacturing output makes up the difference, $MS_0 = MD_0 - MN_0$, at the price of PM_0. This, of course, assumes that it is feasible for South to produce MS_0 given its labour endowment.

Climate Change and Agriculture

The buildup of emissions over time is assumed to cause changes in climate leading to reduced agricultural productivity. As a benchmark, we consider the case where agricultural output per worker falls by the same proportion in both countries, say by 10 percent. In response to the decline in agricultural productivity, the break-even curves for agriculture in North and South, BEA_N and BEA_S in figure 1, shift downward by 10 percent since the agricultural sector is no longer able to afford the initial wages, WN_0 and WS_0. Indeed, wages must fall by 10 percent in each country for agriculture to break even. The immediate effect of declining agricultural output is a situation of excess demand for the agricultural good and excess supply of the manufactured good. In response, the price of the manufactured good measured relative to the agricultural good must decline by exactly 10 percent if South is to remain diversified. If the price of the manufactured good falls by less (more) than 10 percent, South will specialize completely in manufacturing (agriculture). A 10 percent decrease in the price of the manufactured good shifts the break-even curves for the manufacturing sector in each country inward toward the origin by 10 percent because the sector must pay 10 percent less for its inputs if it is to break even. The wage in South and the wage and the emission price in North, thus, fall by 10 percent relative to the agricultural good but remain unchanged in terms of the manufactured good. The manufacturing price line and the Northern supply curve shown in figure 2 shift downward by 10 percent, leaving manufacturing output in North unchanged. Supposing for a moment that the demand for the manufactured good were independent of income, consumption of the manufactured good would increase unambiguously and new output and additional emissions would be forthcoming from South. In the case where the demand for the manufactured good is independent of income, therefore, the general equilibrium effects of declining agricultural productivity unambiguously lead to accelerated climate change.[8]

Fortunately, income effects in demand are likely to mitigate and could conceivably reverse the trend toward accelerated climate change. The income elasticity of demand for the manufactured good is likely to exceed that for the agricultural good. Consequently, the decline in real income associated with reduced agricultural productivity will shift the demand curve for the manufactured good inward in figure 2 and at least partially offset the increase in consumption associated with the lower price. The general equilibrium effects of reduced agricultural productivity will only result in deceleration, rather than acceleration, in the accumulation of GHGs and the pace of climate change if the income effect is sufficiently strong that consumption of the manufactured good actually declines. While the possibility of accelerated climate change through the adverse effect of emissions on agricultural productivity arises in the context of a simple model, this analysis should prompt further general-equilibrium research. Such research is particularly important since the degree of decrease in agricultural productivity is likely to be highly asymmetric across regions, with some regions actually gaining.

Northern Emission Reductions under the Kyoto Agreement

A key feature of the Kyoto Protocol is that the Annex I countries, consisting of developed countries and transition economies, commit to reductions in GHG emissions. While developing countries may face future limits to emissions, they remain unconstrained under the first round of commitments specified by the Kyoto Protocol. To aid in understanding the Kyoto Protocol, therefore, we explore the impact of tightening North's emissions cap in the context of our model.

The reduction in North's aggregate emissions cannot affect wages in either country, the price of emissions in North or the world price of the manufactured good, because the break-even curves in figure 1 all remain unchanged due to the sequential structure of the equilibrium, which was discussed previously. In figure 2, North's manufacturing supply curve, S_N, shifts to the left due to the tighter emissions constraint. North's aggregate output declines as Northern firms are driven to exit from the manufacturing sector. Since South's supply of the manufactured product is perfectly elastic at the price of PM_0, there is, however, an exactly offsetting increase in the aggregate output of South as new manufacturing firms enter the sector. As a result, global emissions unambiguously increase as relatively clean Northern manufacturing firms are displaced by relatively dirty Southern ones. The exemption of South from emissions constraints thus leads definitively to global carbon leakage in our simple general equilibrium model.

Here it is interesting to observe that the refusal of the United States to ratify the Kyoto Protocol may actually reduce the extent of this global carbon leakage. If the United States does not unilaterally tighten its emission constraint, the magnitude of the leftward shift in the Northern supply curve in figure 2 will be reduced. Consequently, the degree of displacement of manufacturing production from the relatively clean North to the relatively dirty South will be reduced and global emissions will increase to a lesser extent. These strong unambiguous results do depend on the fact that there are two goods, but only one conventional factor, namely labour, in addition to emissions. If the number of inputs excluding emissions were greater than or equal to the number of goods, however, South's supply curve would not be perfectly elastic; South's manufacturing output would rise by a lesser magnitude than the North's decline and thereby at least open the possibility of a decline in global emissions.

Emission Credits under the Kyoto Agreement

Another important feature of the Kyoto Protocol, the clean development mechanism (CDM), allows Northern firms to buy *emission credits* from Southern firms when the latter commit to adopting cleaner production techniques. Essentially, a Northern firm pays a Southern firm to reduce emissions and the credit allows it to increase emissions by the same magnitude. As a starting point, assume that North has already tightened its emissions cap, leading to increased manufacturing output in South and increased global emissions as discussed in the previous section. Prior to the opening of trade in credits, therefore, the price of emissions is positive in North but equal to zero in South. An unrestricted credit system would equalize emissions prices in North and South, resulting in a fully integrated world emissions market. Alternatively, restricted credit systems are also possible. For example, the European Union and many environmentalists favoured so-called *supplementarity* restrictions, which would have limited the use of credits in achieving national emission targets (Pancoast, 2003). Such a restricted credit system would prevent full integration of the world emissions market and retain a distortion.

Much of our focus now turns to the number of manufacturing firms, especially those in South. Recall that xs^o denotes the emissions level of each Southern firm before trade in emissions credits begins. The effect of credits on global emissions depends critically on whether there is entry or exit from Southern manufacturing. This is because each additional Southern firm adds xs^o emissions to the world total, either directly by way of its own emissions or indirectly by selling credits that allow Northern firms to emit more.[9] The entry of additional Northern firms does not have a similar effect because entrants, like incumbents, fall under North's aggregate cap. The only way that the Northern manufacturing sector can increase emissions above this cap is by purchasing credits from Southern firms.

Implementation of either an unrestricted or restricted credit system affects world goods markets by enhancing the efficiency of the manufacturing sector. As the underlying markets for emissions become more integrated with manufacturing firms in North compensating those in South for their reductions in emissions, the opportunity cost and long-run equilibrium price of the manufactured good decline. The lower price of the manufactured good, in turn, increases consumption and necessitates entry into the manufacturing sector in at least one country. If the ratio of manufacturing firms in South relative to North remains constant, there will be entry into manufacturing in both North and South, with the latter causing increased world emissions.

The ratio of the number of manufacturing firms in South relative to North, however, may change in either direction due to the integration of world emissions markets. Implementing a credit system causes the emissions prices in North and South to equalize or at least converge. As the emissions price in North declines, the demand for credits per Northern firm rises, and as the emissions price increases in South, the supply of credits per Southern firm rises. If the magnitude of the former effect aggregated over the initial number of firms in North is greater (smaller) than the latter effect aggregated over the firms in South, there will be excess demand for (supply of) credits and the equilibration of the emissions market will require an increase (decrease) in the number of manufacturing firms in South relative to that in North.

To equilibrate both the world emissions market and the world goods market when the credit system is introduced, entry into manufacturing must occur in at least one country and may well occur in both countries. With overall world manufacturing output increasing, a decrease in the ratio of manufacturing firms in South relative to North is a necessary but by no means sufficient condition for a reduction in the number of Southern manufacturing firms and a corresponding reduction in global emissions. Consequently, there is a strong possibility that the credit system will lead to entry into Southern manufacturing and a concomitant increase in world emissions. Since the increase in global emissions arising from the new more stringent Northern emissions cap preceded this analysis, it follows that the credit system in the Kyoto agreement may *further* worsen global carbon leakage.

Policy Synopsis

While the Kyoto agreement has frequently been criticized on economic efficiency grounds, the importance of the climate change issue has convinced many observers that it is time to move forward for environmental reasons notwithstanding any economic shortcomings. The current article questions the view that the Kyoto agreement is sufficiently good for the environment that it should be implemented with haste. Ironically the Kyoto agreement may actually exacerbate the environmental problem it is intended to mitigate. By design, the model used in this article provides a simple general equilibrium framework. Undoubtedly, adding policy details and modeling complications may qualify the strong results concerning global carbon leakage. Even so, the analysis should sound an important note of caution concerning the potential effects of the Kyoto Protocol on climate change.

Endnotes

[1] The authors gratefully acknowledge support from the Institute for Advanced Policy Research (IAPR) at the University of Calgary. The analysis and views expressed in this paper, however, do not necessarily reflect those of the IAPR or the University of Calgary.

[2] Of course, the impact on agriculture will not be uniformly negative; certain regions or subregions stand to gain. While there have been mixed results reported for Canadian regions and Canada as a whole, a recent study by Weber and Hauer (2003) predicts *positive* effects.

[3] Many of the results in international economics depend on the number of tradables, usually goods, versus non-tradables, usually factors (Dixit and Norman, 1980). Consequently, adding additional inputs such as land without adding additional goods weakens some of the results of the model as discussed below. Capital could be added without substantive changes, however, if it were assumed to be fully mobile between countries.

[4] It would be straightforward to allow international pollution spillovers such as acid rain.

[5] This implies that, prior to Kyoto, there were indirect controls on GHG emissions in place in North, but not South, through abatement measures on other air pollutants.

[6] Carbon sequestration in soils is enhanced with the introduction of minimum tillage techniques, long-term planting activities, etc. It should be recognized that sequestration is not guaranteed to provide a permanent reduction of GHGs. The sequestered carbon dioxide can be re-released to the atmosphere with the re-introduction of intensive tillage techniques, for instance.

[7] Since South has a one-factor (Ricardian) technology with a linear production possibility frontier, PM_0 is the unique price at which South can be diversified or produce both goods. It is noteworthy that South's break-even curve for the manufacturing sector, BEM_S:PM_0, remains negatively sloped. Suppose that South introduced a Pigouvian tax policy such that its emissions price VS rose above zero. With the price of the manufacture constant at PM_0, South's wage would have to fall if its manufacturing sector were to continue to break even.

[8] This is before consideration of any lost or reversed sequestration effects arising from declining agricultural activity, which would further contribute to accelerated climate change.

[9] The CDM rules require additional emission reductions compared to the business-as-usual baseline at the project level. There are also measures to control for leakage or displacement of emissions within the defined boundaries of the specified project. Importantly, however, CDM does not have sufficient measures in place to constrain emissions at the economy-wide level; thus, the entry of new (polluting) firms opens the possibility of an overall increase in South emissions.

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