Effects of GHG Mitigation Policies on Livestock Sectors

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1. Introduction

Taking into account the entire livestock commodity chain – from land use and feed production, to livestock farming and waste management, to products processing and transportation – about 18 percent of global anthropogenic greenhouse gas (GHG) emissions can be attributed to the livestock sector (Steinfeld *et al*., 2006). Furthermore, global CH_4 emissions from livestock production alone are expected to increase by around 30% between 2000 and 2020, in response to strong growth in demand for meat and dairy products (USEPA, 2006a). Developing countries, which contribute more than two thirds of current emissions, are expected to account for most of this increase. This suggests that any strategy for reducing global GHG emissions should consider the livestock sector, and should not exclude developing countries. This report focuses attention on this under-investigated aspect of global climate change, namely GHG emissions from livestock production in developing, as well as developed countries.

Large differences in GHG emissions per unit of output (emission intensity) and mitigation potentials between regions, commodities, and production technologies mean that

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global mitigation policies could generate significant changes in the global distribution of livestock production, trade and consumption (Avetisyan et al., 2010), with attendant impacts on the well-being of farm households as well as consumers of livestock products. While mitigation policies should improve societal welfare, by internalizing some of the costs of climate change, the ensuing distributional consequences will strongly influence the various countries' and livestock sectors' willingness to take part in global mitigation solutions. An understanding of these distributional effects will therefore assist in designing mechanisms to encourage participation and address equity concerns. The goal of this project is to assess such impacts via a global economic analysis undertaken with a modified version of the GTAP computable general equilibrium (CGE) model of global trade, production, consumption and GHG emissions.

Further, mitigation policies in the livestock sector are unlikely to be implemented in isolation from climate policies in other agricultural sectors, as well as non-agricultural sectors such as forestry, energy and transport sectors. Interactions between these sectors under various climate policy regimes could have important consequences for sectors that share scarce resources. For example, competition for land resources between livestock sectors and other land using sectors will be critical in shaping the post-mitigation global geography of livestock production. Taxes on fossil fuel emissions will also affect the costs of production and transportation of livestock inputs and outputs.

The project builds on a global general equilibrium (GE) model (GTAP-AEZ-GHG) documented in Golub *et al.* (2009). This is a unified modeling framework that links the agricultural, forestry, food processing, manufacturing and services sectors through land, labor and capital markets, consumers' budget constraints, as well as through international trade. The model also incorporates different land-types, land uses and related GHG emissions and sequestration, and mitigation options as identified by the US-EPA(2006).

For the present paper, we extend the 3 region model of Golub *et al*. (2009) to 19 regions, and generate estimates of global livestock GHG abatement potential over the medium term (for a representative year with a 20-year time horizon), and provide information about the global reorganization of livestock production, following the introduction of a carbon price in agriculture, forestry and other sectors. We consider a broad range of mitigation policies, which reflect global initiatives being considered under the United Nations Framework Convention on Climate Change (UNFCCC). Given the recent commitment of funds to reduce deforestation and the conspicuous absence of agriculture in the Copenhagen Accord, the indirect impacts on agriculture of climate policies implemented in other sectors are examined. Further, given that Non-Annex I countries are not subject to emission targets under the Kyoto Protocol, we model the impacts of mitigation policies that apply to Annex I countries only, as well as those that apply to both Annex I and Non-Annex I countries. We also extend the modeling framework to accommodate an abatement subsidy, given that payment for mitigation activities through offset programs (e.g. the Clean Development Mechanism) may be a more likely option than carbon taxes for achieving mitigation in agriculture.

Methodology

Modeling approach

We build on the GTAP-AEZ-GHG model described in Golub et al. (2009). Those authors start from the basic GTAP-E CGE model (developed by Burniaux and Truong (2002), as modified by McDougall and Golub (2007)) and as validated by Beckman et al. (2010), and added unique regional land types -- Agro-Ecological Zones (AEZs) (Lee et al., 2009) and detailed non-CO_2 GHG emissions for all sectors of the economy (Rose and Lee, 2009), with emphasis placed on land-based GHG emissions and forest carbon sequestration.

The explicit treatment of GHG mitigation options is based on a series of partial equilibrium studies of specific sectors' abatement options. In the agricultural sectors, the model is calibrated based on non-CO_2 GHG mitigation possibilities derived from detailed engineering and agronomic studies developed by the US Environmental Protection Agency (USEPA, 2006). The agricultural production structure in this model allows for more refined mitigation responses than currently available in the CGE literature. For example, in the model abatement can occur by reducing overall fertilizer use, as well as by changing the way in which fertilizer is applied.

In the case of forest carbon sequestration, the estimates of optimal sequestration responses to global forest carbon subsidies are derived from the modified Global Timber Model of Sohngen and Mendelsohn (2007). Then, the CGE model's regional responses are calibrated to the forest carbon supply curves. These responses include both the extensive margin (increased forest land cover) and intensive margin (increased carbon stocks on existing forest lands due to modifications of rotation ages of harvesting trees and management) of forest carbon sequestration.

The analysis is conducted using a 19 region aggregation of the GTAP data base (see Table A1 in Appendix for regional aggregation) and it utilizes version 6 of the GTAP data base representing the world economy in 2001. We use the v.6 data base, since GHG emissions and land use are only now being updated to the v.7, 2004 data base. We also include CO_2 emissions from fossil fuel combustion (Lee, 2007) linked to underlying economic activity, to allow for rigorous consideration of the trade-offs between emissions reduction in land using sectors, on the one hand, and from fossil fuels combustion and industrial activities, on the other.

Heterogeneous land

When modeling competition for land, it is important to recognize that land is a heterogeneous endowment. To reflect this, we bring in climatic and agronomic information by introducing AEZs (Lee *et al*., 2009). We distinguish 18 AEZs, which differ along two dimensions: growing period (6 categories of 60 day growing period intervals), and climatic zones (3 categories: tropical, temperate and boreal). Following the work of the FAO and IIASA (2000), the length of growing period depends on temperature, precipitation, soil characteristics and topography. The concept "length of growing period" refers to the number of days within a year of temperatures above 5^{o}C when moisture conditions are considered adequate for crop production. This approach evaluates the suitability of each AEZ for production of crops, livestock and forestry based on currently observed practices, so that the competition for land within a given AEZ across uses is constrained to include activities that have been historically observed to take place in that AEZ. Indeed, if two uses (e.g., citrus groves and wheat) do not presently appear in the same AEZ, then they will not compete in the land market.

The different AEZs enter as inputs into a national production function for each land using sector. With a sufficiently high elasticity of substitution in use, the returns to land across AEZs, but within a given use, will move closely together as would be expected if production of all homogeneous national commodities occurred directly at the AEZ level (Hertel et al., 2009).

Even after disaggregating land use by AEZ, there remains substantial heterogeneity within AEZs. In addition, there are numerous barriers to land conversion between agriculture and forestry, as well as within agriculture -- say between crop and livestock uses. Therefore, we limit the potential for movement of land from one use to another within an AEZ. In the model, the allocation of land is determined through a nested constant elasticity of transformation (CET), multi-stage optimization structure (Ahammad and Mi, 2005). The rent-maximizing land owner first decides on the allocation of land among three land cover types, i.e. forest, cropland and grazing land, based on relative returns to land. The land owner then decides on the allocation of land between various crops, again based on relative returns in crop sectors. The CET parameter among three land cover types is set to -0.5. The absolute value of this parameter represents the *upper bound* (the case of an infinitesimal share for that use) on the elasticity of supply to a given use of land in response to a change in its rental rate. The more dominant a given use in total land revenue, the smaller its own-price elasticity of acreage supply. The lower bound on this supply elasticity is zero (whereby all land is already devoted to that activity). Therefore, the actual supply elasticity is dependent on the relative importance (measured by land rents share) of a given land use in the overall market for land and is therefore endogenous. The CET parameter governing the ease of land mobility across crops is set twice larger. As with the land cover elasticity, this represents the upper bound on crop acreage response to an increase in the rental rate on a specific crop type. The lower bound is zero (when all crop land in an AEZ is devoted to a single crop).

GHG emissions

Data on anthropogenic fossil fuel combustion CO_2 and all non-CO_2 GHG emissions for the 19 model regions are provided in Table 1. Globally, non-CO_2 emissions represent about one third of CO_2 GHG emissions, with China and USA as leading contributors. More than half of all non-CO_2 emissions are related to agricultural activity. A detailed breakdown of non-CO_2 emissions from the agricultural sectors by region is provided in Figure 1. Livestock production makes a significant contribution to agricultural emissions in all regions (63% of the agricultural emissions in total), and China[2] and Sub Saharan Africa are the largest contributors with 20% and 13% of global non-CO_2 emissions from agriculture, respectively. These two regions are also the largest contributors of global non-CO_2 emissions from the livestock sectors, and the ruminant sector in Sub Saharan Africa is single largest agricultural source of non-CO_2 emissions globally. In China and Rest of South East Asia (R_SE_Asia) paddy rice cultivation is an important source of methane emissions.

To model and evaluate the general equilibrium input allocation responses to mitigation policies, we tied emissions to explicit input or output flows. Three types of agricultural production mitigation responses are captured: those associated with intermediate input use (e.g. fertilizer), primary factors (e.g., land in paddy rice production), and those associated with sector outputs (e.g., burning of crop residues). Emissions associated with enteric fermentation, manure management in ruminants and non-ruminants are tied to livestock output in order to better facilitate calibration to EPA's abatement cost estimates (see footnote 4 below for a discussion of this point). Emissions from biomass burning, and stationary and mobile combustion are tied to sector output. Input related emissions are not always restricted to be released in fixed proportion to the amount of input used. We introduce an additional layer of substitution possibilities in the production structure to reflect changes in production practices which reduce the intensity of input-related emissions. Thus, for example, paddy rice producers are permitted to respond to a methane emissions tax not only by using less land, but also by changing the emissions intensity of paddy rice land, and similarly for fertilizer use in coarse grains production, whereby producers

[2] Includes Hong Kong.

can increase the frequency of application (while keeping total use fixed) to mitigate nitrous oxide emissions.

Any given emissions entry in Figure 1 may be large because the economic activity in the sector is large (e.g., a large dairy sector), and/or there is a high level of emissions per dollar of activity. The latter is termed the “emissions intensity” of a given activity, and this intensity is critical in determining the impact of a carbon-equivalent emissions tax on a given sector. As shown in figure 2, emission intensities per dollar of output (kgCO_2eq/$) (when all non-$CO_2$ emissions in livestock sectors, including those related to output, factors and intermediate inputs use, are tied to output) of the ruminant sector are significantly higher than the emission intensities of non-ruminant production in all regions and of the dairy production in all regions except Sub Saharan Africa. Rest of Southeast Asia (R_SE_Asia), Brazil, Malaysia and Indonesia, Sub Saharan Africa (S_S_Afr), India and Rest of South Asia (R_S_Asia), have highest ruminant sector emission intensities.

There is also great variation in emissions intensities within a given sector, across countries. Ruminant meat production intensities vary by more than an order of magnitude, with the lowest intensities in USA, East Asia and Europe. Avetisyan et al. (2010) investigate this phenomenon in great detail. They decompose emissions per dollar of output into emissions per animal and value of output per animal and show that most of the variation in emissions intensities may be attributed to differences in the value of annual output per animal. Countries with highly productive livestock industries naturally have much lower economic emissions intensities.

In addition to the emissions intensities, the economic impacts of the climate policy on each sector also depend on their marginal costs of abating emissions. As discussed, the model used in this study relies on marginal costs associated with alternative abatement strategies for key non-CO_2 emissions sources — livestock enteric and manure emissions, paddy rice, and other grains (wheat, maize, soybean) — estimated by the U.S. Environmental Protection Agency (USEPA, 2006). Figure 3 summarizes the percentage abatement response for the livestock sectors in each region at a marginal cost of 27 $/tCO2-eq. The information was derived by the authors from estimated USEPA(2006) abatement costs for 2010 and customized for our model's sector and regional aggregation. This figure demonstrates that, while the emissions contribution of the non-ruminant sector is small relative to other livestock sectors (Figure 2), the capacity for abatement, in percentage terms, is higher for this sector than for dairy farms and ruminant meat production in most regions. By comparison, the ruminant sector has much fewer abatement opportunities, in percentage terms, in most regions, but larger absolute potential. Combining the emissions and abatement possibilities summarized in Figures 1 to 3, we would expect to see the ruminant sectors of Brazil and Sub Saharan Africa most negatively affected by the imposition of region-wide emissions tax, and the non-ruminant sectors of regions such as the US, EU and India least affected.

The CGE model used in this study is calibrated to the USEPA (2006) marginal abatement cost (MAC) curves that correspond to the model region and sector structure. For livestock sectors we use new information on abatement opportunities summarized in Figure 3. In the crop sectors we apply parameters reported in Golub et al. (2009).[3] The calibration procedure is

[3] Because of more disaggregated data used in this project, we apply Rest of the World (ROW) parameters reported in the previous work to all regions other than China and USA. In future versions of this paper, we plan to calibrate

described in Golub et al. (2009) and operates by adjusting the elasticities of substitution between emissions and respective inputs/outputs in order to replicate the USEPA abatement possibility estimates at 27$/t$CO_2$eq.[4]

Results

Having calibrated the GTAP-AEZ-GHG model to a suite of partial equilibrium GHG abatement costs, we now deploy our CGE model to investigate the market interactions between these different abatement opportunities. This is the focal point of our paper. We summarize these interactions with general equilibrium GHG abatement supply schedules. The general equilibrium supply schedules are derived by varying the per unit carbon tax incrementally up to $50/t$CO_2$eq in all sectors and regions of the global economy. Figure 4 portrays the global abatement supply, including all GHG emissions and sequestration -- non-CO_2 emissions from agriculture, forest carbon sequestration, energy industrial CO_2 and non-CO_2 GHG, and emissions from private consumption -- taking into account full general equilibrium adjustments. At 27$/t$CO_2$eq, the model predicts that global emissions can be reduced by 12 GtCO_2eq with almost half of the reduction provided by sequestration in forests (5 GtCO_2eq) and 1.2 GtCO_2eq

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each of 17 regions (currently all sharing the same ROW parameters), as well as several of the new sectors to more disaggregated marginal abatement curves when they become available.

[4] More specifically, we begin the calibration process for input-related agricultural emissions by introducing the elasticities of substitution in production, both amongst intermediate inputs and value-added and between elements of value-added. We calibrate the elasticities using econometric estimates reported in a survey of the econometric literature by the OECD (2001) and the approach suggested by Keeney and Hertel (2005). We then fix output levels in the sectors, as well as input prices to match the partial equilibrium assumptions of the engineering cost estimates, and proceed to vary the carbon equivalent price to map out a partial equilibrium abatement response for the relevant sector in each region. This response is compared to that of the USEPA prediction at 27$/t$CO_2$eq. In the process of calibration, in Golub et al. (2009) for the N_2O emissions from fertilizer use in the crops sectors, the two abatement cost estimates were in good agreement, so no further adjustment was required. However, in the case of methane emissions from paddy rice production, the level of abatement predicted by the model is too low – the econometrically estimated production function parameters suggest less scope for abatement than the USEPA estimates. In this case, the possibility of changes in the input emissions intensity was added via introduced substitution between land and methane emissions in paddy rice production. In the case of non-CO_2 emissions from the livestock sectors, the econometrically estimated production function gives too large an abatement response. For these sectors, emissions were tied to output, and the substitution elasticity between emissions and the input aggregate was calibrated to replicate the USEPA abatement estimate.

abatement provided by agricultural sectors. The *direct emission reduction* from livestock is 0.8 $GtCO_2eq$, or about 62% of abatement in agriculture and 6% of global emissions reduction. The magnitude of the potential forest and agriculture abatement possibilities highlights the importance of devoting greater attention to these sources of future mitigation. To date, most studies have focused heavily on the industrial, residential, commercial and transport abatement of fossil fuel-based emissions. However, in our analysis, these account for only half of the total economic abatement potential. Mitigation in the land-based activities related to agriculture and forestry account for the other half of abatement possibilities at moderate levels of carbon taxation.

Having this abatement overview firmly in mind, we now turn to the analysis of three alternative mitigation policy scenarios, as described in Table 2. In all three of these scenarios, we put a price on global forest carbon emissions and sequestration, taxing emissions and providing payments for sequestration. The scenarios are differentiated according to participation of the agriculture sectors as well as the participation of non-Annex I countries. In scenario 1, a carbon price policy of 27$/$tCO_2eq$ is applied to all sectors. In this setting, the world is able to take advantage of all mitigation possibilities. Indeed, the greater the number of sectors and regions that the abatement policies cover, the lower the average cost of CO_2eq tonnes abated will be for a given mitigation quantity (e.g., de la Chesnaye and Weyant, 2006).[5]

However, the global application of an emissions tax is unlikely to be politically acceptable, particularly among developing countries, where near term food security and development concerns justifiably take priority over the economically efficient management of

[5] Put another way, for a given abatement quantity, the total cost of a policy scenario that targets all regions and sectors will be lower than any policy that targets any subset of these regions and sectors.

long run environmental issues. Consequently, the mitigation responsibilities of countries under the United Nations Framework Convention on Climate Change (UNFCCC) vary according to their economic development status: Annex I countries (industrialized countries and countries in transition) are subjected to mitigation targets which are to be met at their own cost; whereas non-Annex I countries (developing countries) are not subject to mitigation targets, but could potentially receive assistance from industrialized countries to implement abatement measures. Scenarios 2 and 3 fall within the realm of the policy approaches considered under the UNFCCC, as they only levy emission taxes in Annex I regions. In scenario 2, the carbon tax is only applied to Annex I countries, but agriculture is included in this policy. In scenario 3, the agriculture sectors in Annex I countries are left out of the mitigation possibilities, so that the carbon tax applies only to the non-agricultural sectors (and to fossil fuels emissions in agriculture). As noted previously, the global forest carbon sequestration subsidy is applied in all three scenarios.

The results reported in Table 2 provide some important insights. Firstly, note the critical role played by forest carbon sequestration. In scenario 1, this accounts for 40% of global abatement at 27 $/tCO2-eq. And the relative contribution of forest carbon sequestration rises as other abatement options are removed from the policy coverage. When non-Annex I countries are removed from the carbon tax, global forest sequestration's share of the total rises to 60%. Omitting agriculture from the Annex I mitigation effort further reduces global abatement and forest sequestration's share of the total rises to 64% -- nearly two-thirds the world total. This includes significant gains in forest carbon from all types of activities—avoided deforestation, afforestation, and forest management.

A second insight from Table 2 relates to the interplay between agricultural abatement and forest carbon sequestration. When agriculture is exempted from carbon taxation in non-Annex I countries, there is a dramatic reduction in global abatement from agriculture, which drops from 1,204 to just 381 MMtCO2eq – a decline of more than two-thirds. More interestingly, returns to forest carbon sequestration fall (compare scenarios 1 and 2) (compare scenarios 1 and 2). This means that the 27 $/tCO2-eq forest carbon sequestration subsidy buys less abatement because of lost co-benefits from agricultural abatement, and forests global contribution to emissions reductions falls from 4,902 to 4,790 MMtCO2eq.

When agriculture is exempted from abatement in Annex I countries (contrast scenarios 3 and 2), Annex I GHG emissions from agriculture rise by 286 MMtCO2eq (273 – (-13)), while emissions in non-Annex I countries fall more as agricultural activities shift back towards Annex I regions. Thus the global rise in agriculture emissions (381 – 158 = 223 MMtCO2eq) is less than the Annex I change. The reduced pressure on land use in non-Annex I countries means that the same carbon forest sequestration subsidies in the tropics have a greater impact, and total sequestration in non-Annex I countries rises by 27 MMtCO2eq ((4,811–693) – (4,790 –699)).

Before exploring alternative policy instruments in non-Annex I countries, it is useful to take a detailed look at the changes in emissions, output, consumption and trade for agriculture by sector and region in selected scenarios, paying particular attention to the interaction between competing land uses. Tables 3a and 3b summarize the changes in output value and emissions for agricultural sectors according to their location in either Annex I or non-Annex I regions for scenarios 1 and 2. In scenario 1 (Table 3a), which assumes mitigation policies are applied in all sectors, emission intensities improve as emissions fall by more than output in all sectors and regions. This is the purpose of the carbon tax. However, all sectors in non-Annex I regions suffer larger falls in output compared with Annex I regions. This is due to the fact that they have higher emissions intensities (recall Figure 2).

In both dairy and non ruminant sectors output falls by more and emissions by less (in percentage terms) in non-Annex I compared to Annex I regions. In the ruminant sector there are larger emission reductions in non-Annex I regions, however, ruminant output in these regions falls more heavily (in percentage terms) than output of any other sector in both Annex I and non-Annex I regions. Focusing on livestock at the global level, there are larger percentage declines in ruminant sector output compared with non-ruminant output, while percentage changes in emissions between the sectors are similar. This reflects the offsetting effects of higher emission intensities in ruminants, but greater scope for abatement in the non-ruminant sector.

Table 3b summarizes these results for scenario 2, which assumes a global sequestration subsidy for forestry and an emissions tax on all sectors in Annex I only. This time the improvement in environmental efficiencies are largely limited to Annex I regions. In this scenario the agricultural sectors in non-Annex I regions experience very little change in environmental efficiency, as they are not subject to an emissions tax. By comparing the results in tables 3a and 3b, one can see that the foregone improvement in emission intensities in non-Annex I regions, in scenario 2, is matched by a considerable saving in terms of lost output value for agriculture.

Figures 5a and 5b provide a more detailed regional breakdown of changes in output at constant (2001) world prices for the livestock sectors. In scenario 1 (Figure 5a), when the global tax is applied in all sectors, most of the regions experience large reductions in livestock sector output. Dairy output shrinks in all regions (except very small increases in Mala_Indo and Other_Europe regions) and most significantly in Oth_CEE_CIS and India. The ruminant meats sector experiences the largest declines in output value, particularly in Sub Saharan Africa, Brazil and S_O_Amer, whereas ruminant meat production expands in EU27 and Japan. Globally, the fall in the value of non ruminant production is smaller than in ruminant meats sector. However, due to its very large base of non-ruminant meat production, China experiences a steep decline in output value (Figure 5a). Non-ruminant output rises in a few Annex I regions. In scenario 2 (Figure 5b), the output consequences improve markedly for most non-Annex I countries, whereas livestock sectors in the USA, EU and Oceania suffer heavy losses in output value.

Figures 6a and 6b report changes in trade balances in agriculture and forestry sectors by region for scenarios 1 and 2, respectively. The carbon tax changes the pattern of global competitiveness. With the global carbon tax (scenario 1), the US and EU benefit from their low emission intensities in livestock production (Figure 2) and expand their net exports of processed meat (livestock is traded mostly in processed form), while high emission intensity regions such as Brazil and Sub Saharan Africa show a deterioration in their trade balances for this food category, as well as other land based products, and expand their forests operations (forest land, not net exports) in response to the carbon subsidy. Though similar in direction, the changes in sectoral trade balances are much less dramatic in scenario 2, when carbon tax is imposed in Annex I regions only. Figure 6b demonstrates that forest carbon sequestration subsidy bids land away from agriculture in non-Annex 1 and prevent expansion of livestock exports from these countries. As an extreme case, changes in sectoral trade balances of South and Other Americas region (S_O_Amer) are almost identical between scenarios 1 and 2.

Our findings have significant implications for the structuring of policies to achieve cost effective mitigation, without adversely affecting food security and agricultural development needs of non-Annex I countries. In these regions, where agricultural production is land intensive and avoided deforestation and afforestation are low cost abatement strategies, agricultural sectors are more heavily penalized by the introduction of a forest carbon sequestration subsidy than in

Annex I countries (scenario 1). Consequently, the simultaneous introduction of a pecuniary penalty on agricultural emissions could clearly compound economic losses and significantly erode the competitiveness of these sectors in regions that can least afford it. Even in scenario 2, where there is no tax on emissions in non-Annex I, the indirect costs to agriculture are of concern. A potential solution could be to implement a mixed instrument that returns carbon tax revenue to farmers in non-Annex I regions.

Before investigating the application of alternative instruments to manage agriculture emissions, the food security consequences from applying a global forestry subsidy in the absence of policies to support agriculture, are explored by examining the changes in per capita consumption measured at constant food prices by food category and region, under scenario 2 (Figure 6). These results show that, even when agricultural sectors are not directly targeted in non-Annex I regions, these regions experience declines in food consumption. In some regions (e.g. S_O_Amer) the declines are significant.

Abatement subsidy

To account for the possibility that payment for mitigation activities through offset programs (e.g. the Clean Development Mechanism in developing countries) may be more likely to drive mitigation in agriculture than carbon taxes, we extend the modeling framework to accommodate an abatement subsidy. The problem with the subsidy is that we don't have a good idea how large to make this subsidy in order to achieve the desired level of abatement. To overcome this problem, we explicitly impose a carbon tax on input and output related emissions in agriculture in non-Annex I countries, but require that these agricultural producers are reimbursed for the amount of tax they pay. We construct two variants of scenario 1 where a carbon tax is imposed and the forest carbon sequestration subsidy is given globally. But now Annex II countries foot the bill for abatement by non-Annex I agricultural producers (see Table A1 in Appendix for definition of Annex I, Annex II and non-Annex I regions).[6] The relative contribution of each region within the Annex II group is proportional to its regional income.

There are two methods of attaining this non-Annex I abatement. In the first scenario called "output subsidy" in Table 4, the agricultural producers in non-Annex 1 regions are compensated through output subsidy. When carbon tax is imposed, the sum of carbon tax paid by the sector and the output tax/subsidy revenue does not change relative to market value of output. In the second "clean input subsidy" scenario, non-Annex 1 producers are encouraged to use non-emitting inputs (e.g. labor and capital) through introduction of a subsidy to clean inputs. The total amount of subsidy given to each agricultural sector/region is equal to carbon tax paid by the sector/region. In both cases, the subsidy to non-Annex I agricultural producer is paid by Annex II regions.

Table 4 list the results of the "output subsidy", "clean input subsidy" experiments and outcomes of the scenario 1 ("Tax" in the table 4) for comparison. Compared to the tax-only scenario (scenario 1), the output and clean input subsidies are 53% and 66% as effective in controlling livestock emissions, respectively. This is not surprising, because the introduction of the subsidies improves the profitability of livestock producers in non-Annex I regions, resulting in a lower contraction of output (and in some cases an increase in output), compared with the tax-only scenario. The non-dairy ruminant sectors in non-Annex I regions, experience the largest improvements in output following the introduction of the abatement subsidies. Perhaps most

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[6] Given our regional aggregation, it is quite difficult to define regions that are Annex I, but not Annex II. We can't do it perfectly, because 11 out the EU 27 are Annex I, but not Annex II (Bulgaria, Cyprus, Czech Republic, Hungary, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia, Lithuania). We use imperfect Annex II definition that includes all Annex I except Russia.

importantly, reductions in food consumption are less severe in all non-Annex I regions, following the introduction of the subsidies, particularly Brazil and Sub Saharan Africa.

It should be mentioned that much of the improvement in production experienced by non-Annex I countries, is matched by a deterioration in production among the livestock sectors in Annex I countries, following the introduction of abatement subsidies for non-Annex I countries. This is particularly true in the non-dairy ruminant sectors of Canada and Oceania.

Conclusion

In this paper we have investigated effects of GHG mitigation policies on livestock sectors. We used a global computable general equilibrium GTAP-AEZ-GHG model with explicit unique regional land types, land uses and related GHG emissions. The model is then augmented with cost and GHG response information from two partial equilibrium approaches to abatement of land-based greenhouse gas emissions. For agricultural mitigation of GHGs, we calibrate our model to mitigation possibilities derived from detailed engineering and agronomic studies developed by the U.S. Environmental Protection Agency (USEPA, 2006). In the case of forest carbon sequestration, we draw on estimates of optimal sequestration responses to global forest carbon subsidies, derived from the modified Global Timber Model of Sohngen and Mendelsohn (2007).

With this framework we analyze changes in regional livestock output, sector competitiveness and regional food consumption under different climate change mitigation policy regimes. Scenarios we have considered differ by participation/exclusion of agricultural sectors and non-Annex I countries, as well as policy instrument – carbon tax or carbon subsidy. Analysis of the initial data reveals that emission intensities, measured in emissions per dollar of output, differ across livestock sectors and regions. These emission intensities determine where the abatement and reduction in livestock output will take place under the carbon tax scenario. With the carbon subsidy, the link between emission intensity and reduction in output is less apparent. The imposition of carbon tax in agriculture has adverse affects on food consumption, especially in developing countries. The reductions in food consumption are smaller if the agricultural producer subsidy is introduced to compensate for carbon tax the producers pay. Finally, our results highlight importance of forest carbon sequestration. The global forest carbon sequestration subsidy effectively controls emission leakage when carbon tax is imposed only in Annex I regions. The sequestration subsidy bids land away from agriculture in non-Annex 1 regions and prevents expansion of livestock and other agricultural sectors. Though the sequestration subsidy policy allows reduction of GHG emissions, if implemented, the policy may adversely affect food security and agricultural development in developing countries.

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Table 1 CO_2 and Non-CO_2 GHG emissions by region ($MtCO_2eq$)

	Non-CO_2 GHGs			All	CO_2	All
	Nitrous oxide (N_2O)	Methane (CH_4)	F-Gas	non-CO_2	GHG	GHG
USA	402	554	139	1,095	5,985	7,080
EU27	412	457	57	926	3,888	4,814
BRAZIL	184	307	7	497	288	785
CAN	48	94	11	154	540	693
JAPAN	32	20	41	93	1,032	1,124
CHIHKG	641	753	60	1,455	2,918	4,373
INDIA	65	468	8	541	964	1,506
C_C_Amer	44	215	6	264	578	843
S_O_Amer	177	303	4	484	454	938
E_Asia	45	85	20	151	660	811
Mala_Indo	31	202	2	234	416	650
R_SE_Asia	62	260	4	326	363	689
R_S_Asia	84	172	1	256	153	409
Russia	58	297	15	369	1,493	1,862
Oth_CEE_CIS	114	435	5	555	1,001	1,556
Oth_Europe	8	10	4	22	107	128
MEAS_NAfr	117	319	8	443	1,533	1,976
S_S_AFR	315	590	8	913	468	1,381
Oceania	43	152	6	201	426	627
Total	2,881	5,691	405	8,977	23,270	32,247

Table 2 Global and Annex I emissions *reduction* under different policy assumptions, MtCO2eq

Scenario	All emissions reduction		Forest carbon sequestration		Agricultural sectors		Livestock sectors (within agriculture)		Other sectors and private consumption	
	Global	Annex I	Global	Annex I	Global	Annex I	Global	Annex I	Global	Annex I
1. Global forest carbon sequestration subsidy, carbon tax in *all sectors*, *all regions*	12,105	3,720	4,902	686	1,204	230	745	119	5,999	2,804
2. Global forest carbon sequestration subsidy, *Annex I only* tax in all sectors	7,970	3,879	4,790	699	381	273	229	155	2,798	2,907
3. Global forest carbon sequestration subsidy, *Annex I only tax in all non agricultural sectors*	7,566	3,386	4,811	693	158	-13	127	3	2,597	2,707

Table 3a Changes in output (by value at constant world prices) and emissions by agricultural sector, under policy scenario 1

	Dairy	Ruminant	Non ruminant	Paddy rice	Other crops	Total agric.
Annex I						
Δ output (mill. USD)	-$1,827	$474	-$302	$800	-$57	-$911
Δ output %	-2%	1%	0%	4%	0%	-2%
Δ emissions %	-21%	-7%	-23%	-22%	-23%	-17%
Non Annex I						
Δ output (mill. USD)	-$4,394	-$12,162	-$10,214	-$4,556	-$23,522	-$54,847
Δ output %	-6%	-14%	-5%	-5%	-4%	-5%
Δ emissions %	-14%	-27%	-21%	-27%	-18%	-24%
Global						
Δ output (mill. USD)	-$6,221	-$11,688	-$10,515	-$3,756	-$23,579	-$55,759
Δ output %	-4%	-7%	-3%	-4%	-2%	-3%
Δ emissions %	-17%	-23%	-22%	-27%	-20%	-22%

Table 3b Changes in output (by value at constant world prices) and emissions by agricultural sector, under policy scenario 2

	Dairy	Ruminant	Non ruminant	Paddy rice	Other crops	Total agric.
Annex I						
Δ output (mill. USD)	-$2,110	-$4,396	-$1,417	$150	-$690	-$8,462
Δ output %	-2%	-5%	-1%	1%	0%	-1%
Δ emissions %	-21%	-15%	-24%	-27%	-23%	-20%
Non Annex I						
Δ output (mill. USD)	-$639	$213	-$1,178	-$1,008	-$8,845	-$11,457
Δ output %	-1%	0%	-1%	-1%	-1%	-1%
Δ emissions %	-1%	-4%	-1%	-6%	1%	-3%
Global						
Δ output (mill. USD)	-$2,749	-$4,182	-$2,595	-$858	-$9,534	-$19,919
Δ output %	-2%	-2%	-1%	-1%	-1%	-1%
Δ emissions %	-10%	-6%	-8%	-7%	-8%	-7%

Table 4 Changes in food consumption, livestock emissions and output with three alternative instruments

Region	Emissions reduction in agriculture, mill t CO2eq			Emissions reduction in livestock, mill t CO2eq			Change in dairy production, %			Change in non-dairy ruminant production, %			Change in non-ruminant production, %			Change in food consumption, %		
	Tax	Output subsidy	Clean input subsidy	Tax	Output subsidy	Clean input subsidy	Tax	Output subsidy	Clean input subsidy	Tax	Output subsidy	Clean input subsidy	Tax	Output subsidy	Clean input subsidy	Tax	Output subsidy	Clean input subsidy
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*
USA	111	119	118	48	52	52	-1	-2	-2	0	-3	-3	-1	-2	-2	-1	-1	-1
EU27	62	76	74	38	49	47	-1	-2	-2	3	-3	-2	0	-2	-1	-1	-1	-1
BRAZIL	154	75	113	131	57	92	-9	-1	0	-30	-5	-12	-27	-6	-12	-6	0	-1
CAN	8	11	11	3	5	5	-1	-1	-1	-3	-11	-11	2	0	0	-1	-1	-1
JAPAN	2	2	2	1	1	1	0	0	0	5	2	3	2	1	1	0	-1	-1
CHIHKG	208	128	146	79	27	21	-3	-2	-2	-15	1	5	-6	-1	-2	-4	-1	-1
INDIA	84	35	42	58	10	12	-5	-1	-1	-23	1	0	-3	0	0	-3	0	0
C_C_Amer	16	7	8	14	5	6	-3	-1	0	-10	4	5	-1	0	0	-2	-1	-1
S_o_Amer	77	58	59	50	33	33	-9	-5	-4	-13	-5	-4	-7	-3	-2	-5	-3	-3
E_Asia	6	5	5	2	1	2	-2	-1	-1	-2	2	2	-3	-1	-1	-2	-2	-2
Mala_Indo	27	15	25	14	4	10	3	3	5	-27	5	-7	-2	2	1	-2	0	-1
R_SE_Asia	82	35	60	42	5	22	-3	4	8	-43	12	-7	-2	2	1	-2	1	1
R_S_Asia	35	12	15	22	1	2	-3	3	4	-17	4	3	-3	3	3	-2	2	2
Russia	29	29	29	14	14	14	-14	-14	-14	-14	-15	-15	-1	-2	-2	-8	-8	-8
Oth_CEE_CIS	31	23	25	17	11	11	-7	-3	-3	-8	-2	-2	-4	0	0	-2	1	1
Oth_Europe	2	2	2	1	1	1	1	0	0	6	1	1	0	-1	-1	-1	-1	-1
MEAS_NAfr	15	8	9	8	2	2	-2	0	0	-3	5	6	-2	-1	-1	-4	-3	-3
S_S_AFR	239	123	173	191	81	127	-22	3	-4	-22	2	-2	-14	1	-1	-7	1	0
Oceania	17	38	36	15	36	34	-10	-9	-9	0	-23	-21	-4	-7	-6	-2	-3	-2
Total	1204	801	951	745	395	493												

Figure 1 Non-CO_2 GHG emissions by agricultural sector and region ($MtCO_2eq$)

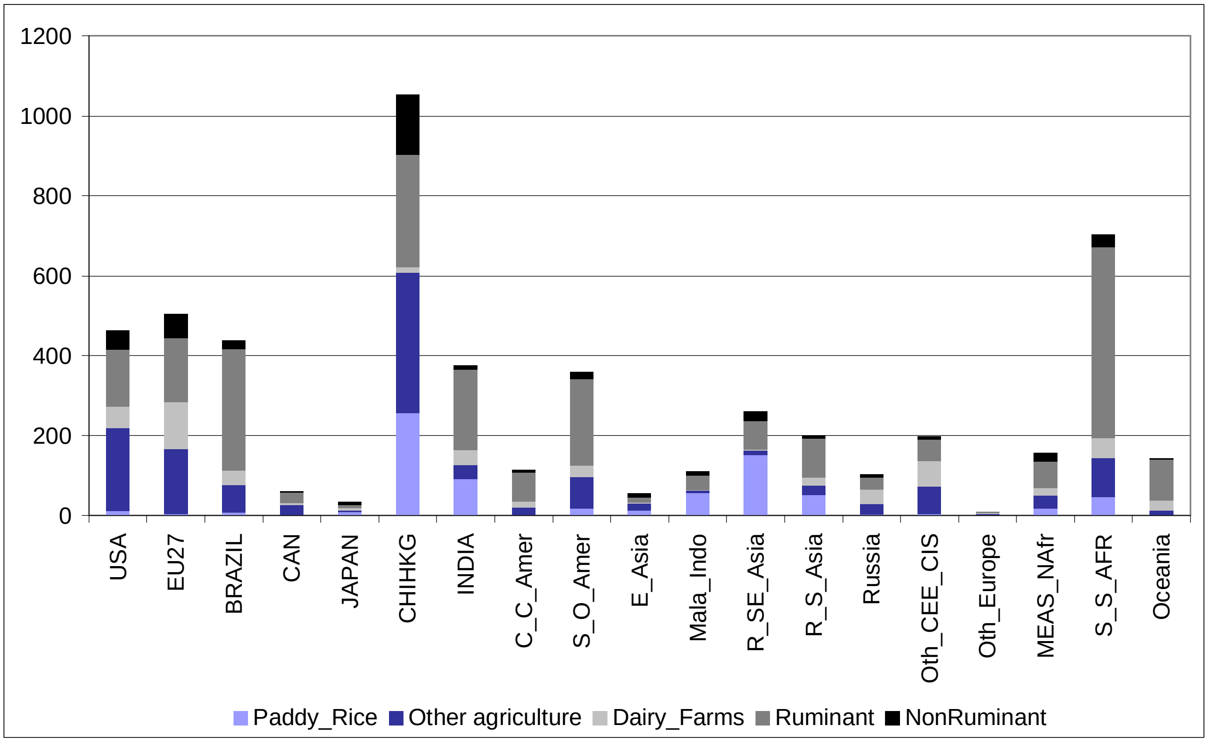


Figure 2 Emission intensity of output when all livestock sector non-CO_2 emissions, including emissions related to factors and intermediate input use, are tied to output ($kgCO_2eq$/$ of output)

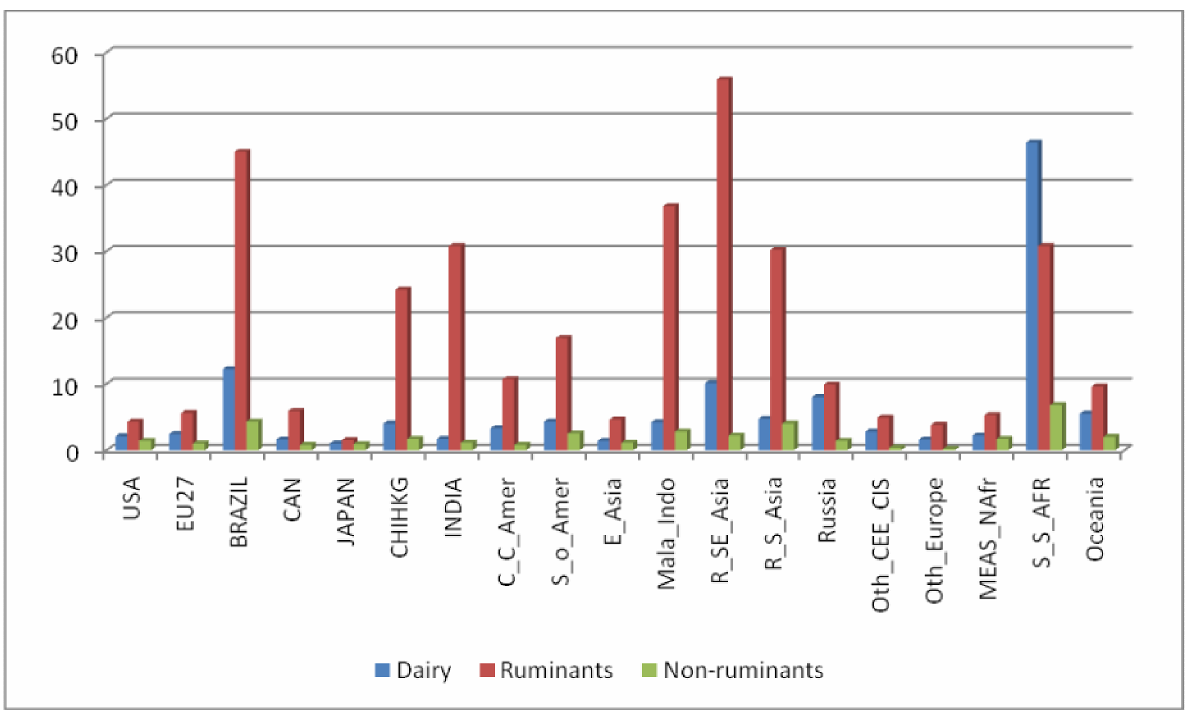
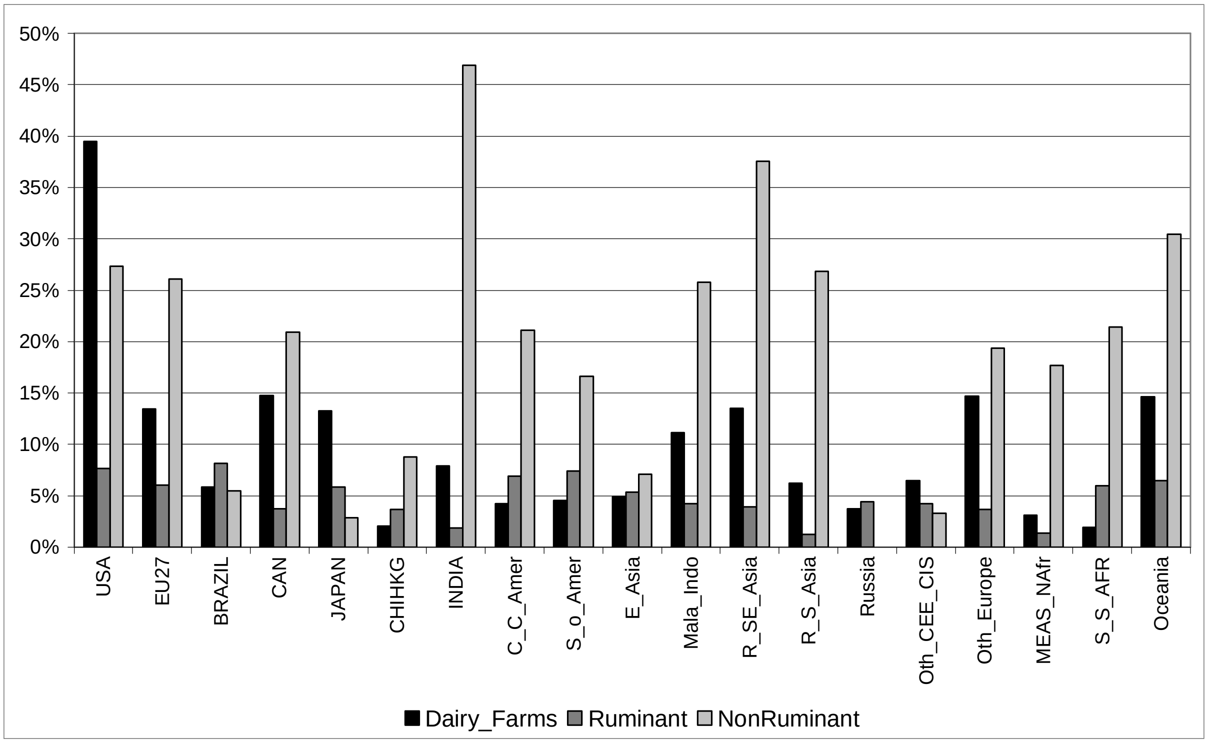


Figure 3: Partial equilibrium % abatement responses for the livestock sectors, at 27 $/tCO$_2$-eq



Source: Derived from USEPA(2006) 2010 detailed abatement cost data.

Figure 4 Global general equilibrium GHG abatement supply schedule: global carbon tax in all sectors, private consumption, and sequestration subsidy in forestry

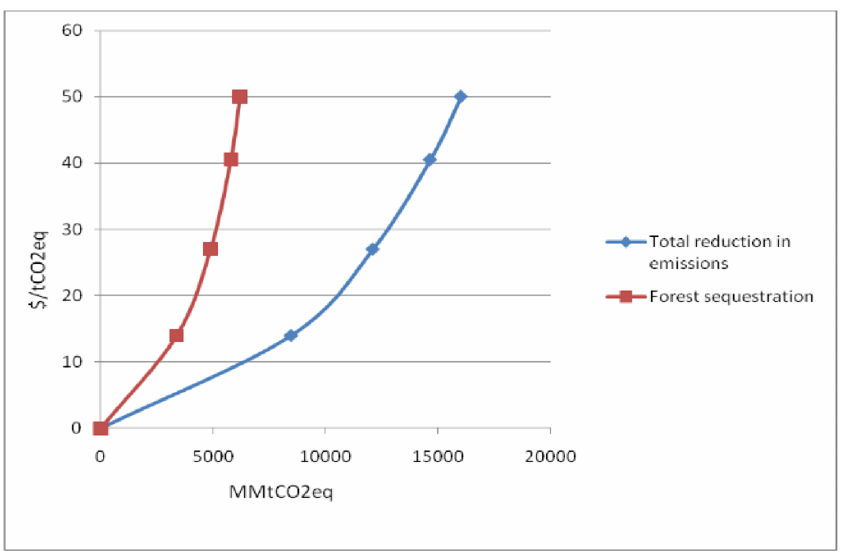


Figure 5a Changes in value of output in livestock sectors at constant world prices when global 27 \$/tCO_2eq tax is imposed in all sectors (mill 2001 US\$)

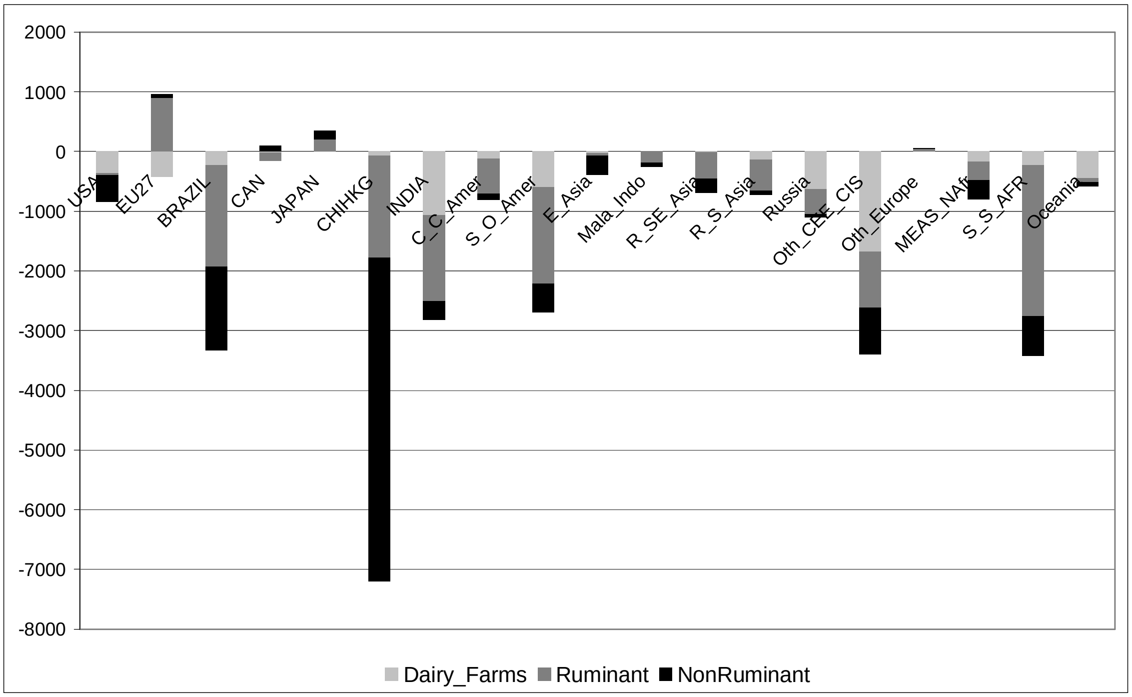


Figure 5b Changes in value of output in livestock sectors at constant world prices when an Annex I-only 27 \$/tCO_2eq tax is imposed in all sectors (mill 2001 US\$)

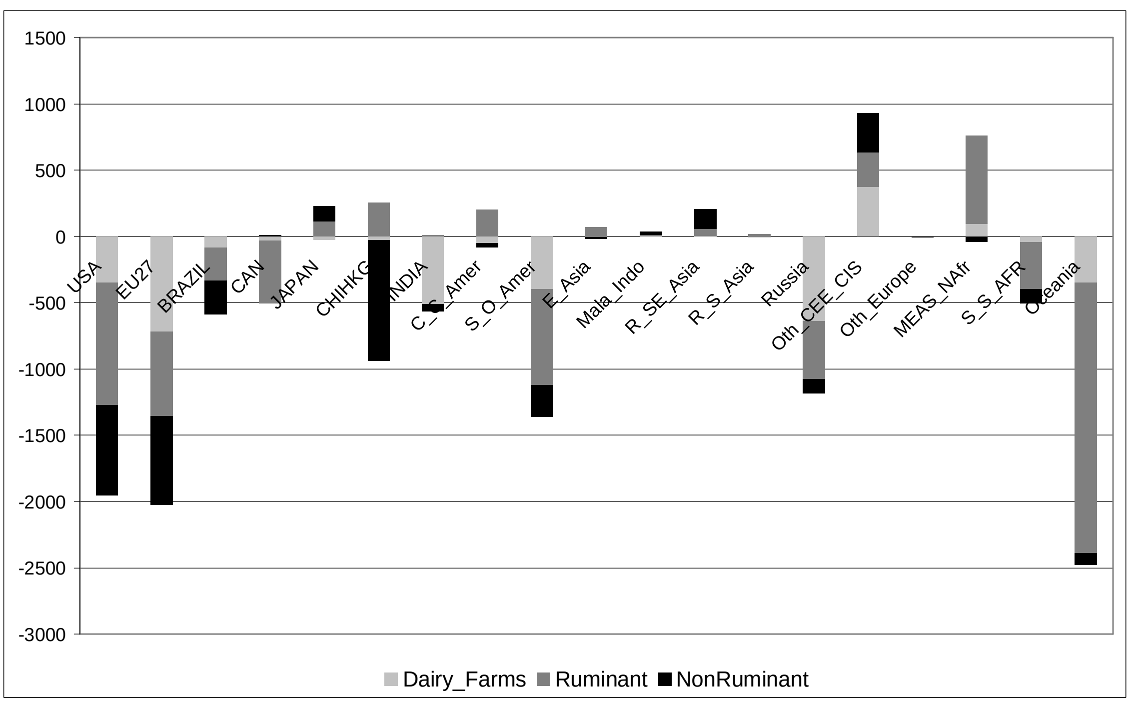


Figure 6a Changes in trade balances in agriculture, forestry and food sectors in scenario 1, by sector and region (mill 2001 US$)

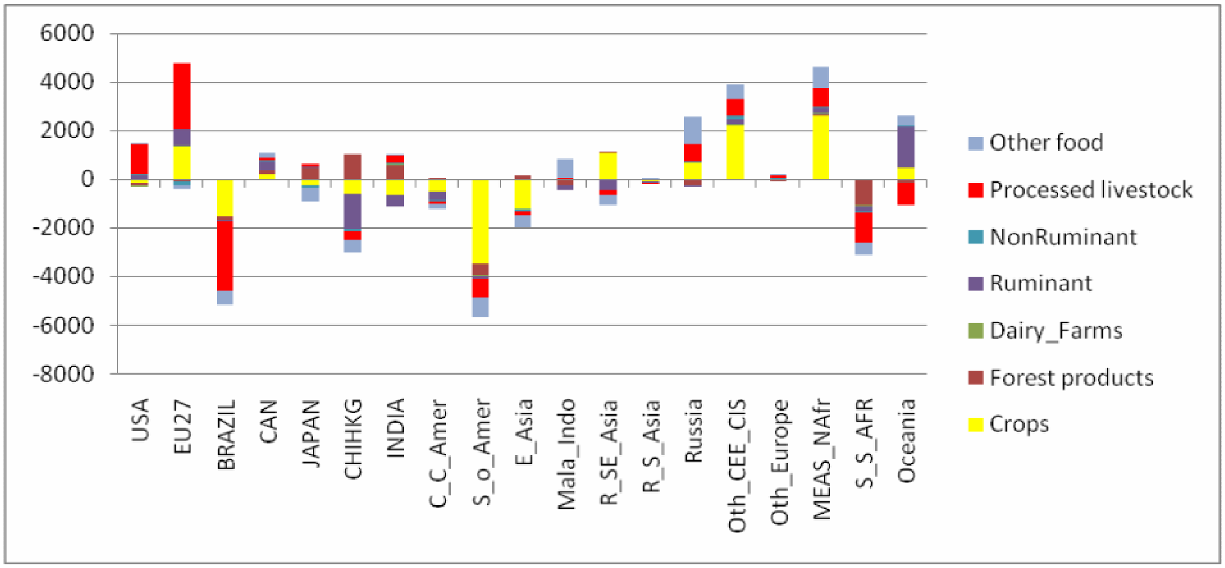


Figure 6b Changes in trade balances in agriculture, forestry and food sectors in scenario 2, by sector and region (mill 2001 US$)

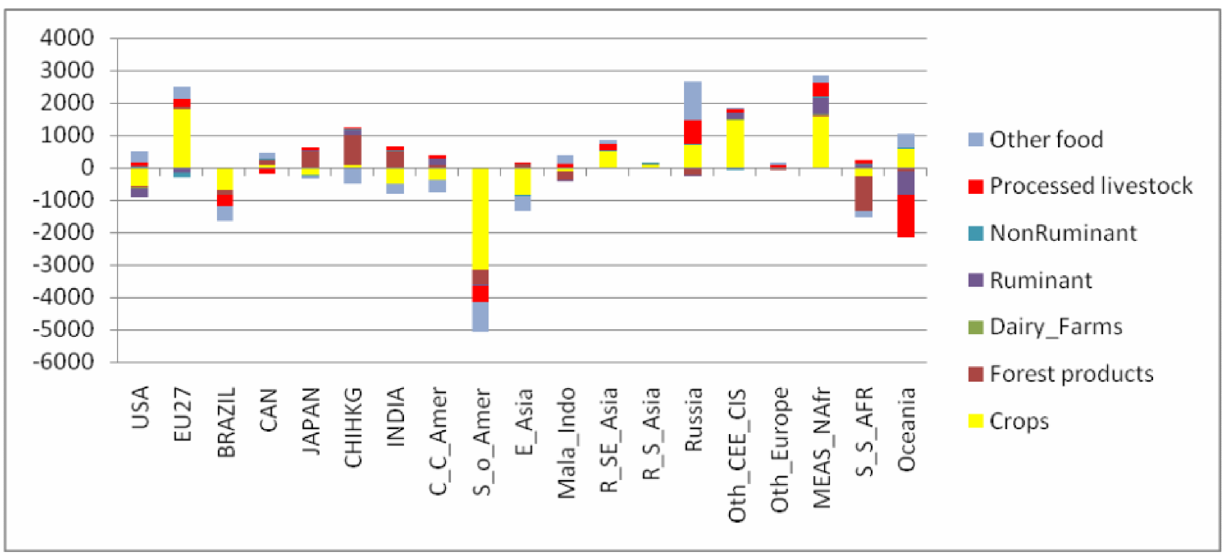
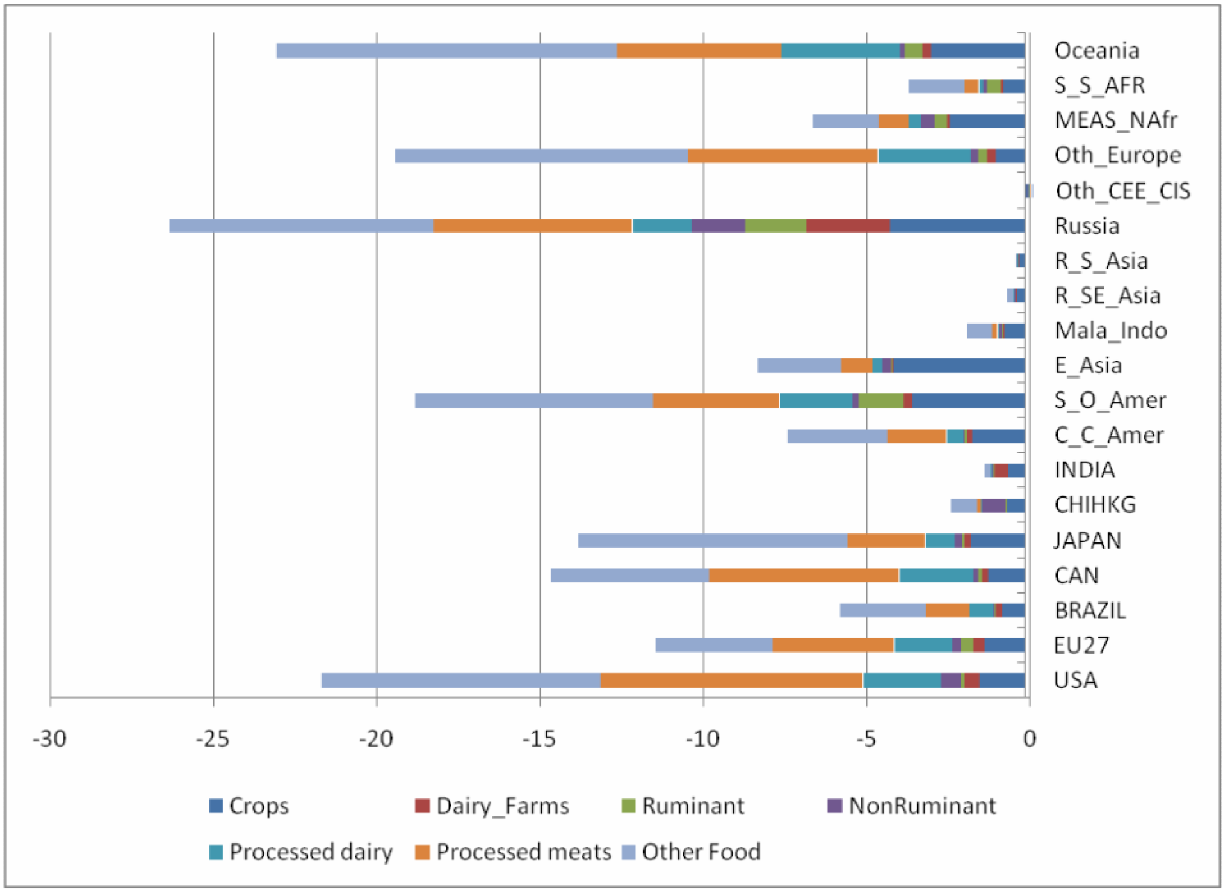


Figure 7 Changes in per capita annual consumption at constant agent prices by food category and region in scenario 2 (2001 US$)



Appendix

Table A1 Aggregation of GTAP regions

Code	Region in the model	GTAP regions	Group
USA	United States	United States	Annex I and II
EU27	European Union 27	Austria, Belgium, Denmark, Finland, France, Germany, United Kingdom, Greece, Ireland, Italy, Luxemburg, Netherlands, Portugal, Spain, Sweden, Cyprus, Czech Republic, Hungary, Malta, Poland, Romania, Slovakia, Slovenia, Estonia, Latvia, Lithuania, Bulgaria	Annex I and II
BRAZIL	Brazil	Brazil	Non-Annex I
CAN	Canada	Canada	Annex I and II
JAPAN	Japan	Japan	Annex I and II
CHIHKG	China, Hong Kong	China, Hong Kong	Non-Annex I
INDIA	India	India	Non-Annex I
C_C_Amer	Central and Caribbean Americas	Mexico, Rest of North America, Central America, Rest of Free Trade Area of the Americas, Rest of the Caribbean	Non-Annex I
S_O_Amer	South and Other Americas	Colombia, Peru, Venezuela, Rest of Andean Pact, Argentina, Chile, Uruguay, Rest of South America	Non-Annex I
E_Asia	East Asia	Korea, Taiwan, Rest of East Asia	Non-Annex I
Mala_Indo	Malaysia and Indonesia	Indonesia, Malaysia	Non-Annex I
R_SE_Asia	Rest of South East Asia	Philippines, Singapore, Thailand, Viet Nam, Rest of Southeast Asia	Non-Annex I
R_S_Asia	Rest of South Asia	Bangladesh, Sri Lanka, Rest of South Asia	Non-Annex I
RUSSIA	Russia	Russian Federation	Annex I
Oth_CEE_CIS	Other East Europe and Rest of Former Soviet Union	Rest of Former Soviet Union, Turkey, Albania, Croatia, Rest of Europe	Non-Annex I
Oth_Europe	Rest of European Countries	Switzerland, Rest of EFTA	Annex I and II
MEAS_NAfr	Middle East and North Africa	Rest of Middle East, Morocco, Tunisia, Rest of North Africa	
S_S_AFR	Sub Saharan Africa	Botswana, South Africa, Rest of South African Customs Union, Malawi, Mozambique, Tanzania, Zambia, Zimbabwe, Rest of Southern African Development Community, Madagascar, Uganda, Rest of Sub-Saharan Africa	Non-Annex I
Oceania	Oceania	Australia, New Zealand, Rest of Oceania	Annex I and II