Effects of carbon-based border tax adjustments on carbon leakage and competitiveness in livestock sectors

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Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's 2012 AAEA Annual Meeting, Seattle, Washington, August 12-14, 2012

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Abstract

Given the likely absence of a "top-down" global agreement after the 2012 expiry of the Kyoto Protocol, many countries (or groups of countries) may only be prepared to introduce a price on GHG emissions if they can maintain the competitiveness of their domestic sectors and prevent leakage effects associated with the expansion of unregulated sectors in other countries. One means of achieving this is through border tax adjustments (BTAs). Most of the studies to date have focused on BTAs in the context of CO_2 combustion emissions from manufacturing sectors. Agricultural sectors, on the other hand, account for a large share of the hitherto under-emphasized non-CO_2 emissions. By drawing on recent research into non- CO_2 emissions and abatement possibilities in the global agriculture and livestock sectors, this paper seeks to complement and extend the existing literature on BTAs. To do this, the paper uses the global computable general equilibrium model GTAP-AEZ-GHG. The analysis shows that BTAs are helpful in controlling loss of competitiveness and emissions leakage in livestock sectors. The study also assesses effect of BTAs on emissions leakage in other sectors and relationship between effectiveness of BTAs and coalition size.

1 Introduction

Given the likely absence of a "top-down" global agreement after the 2012 expiry of the Kyoto Protocol, many countries (or groups of countries) may only be prepared to introduce a price on carbon emissions if they can maintain the competitiveness of their domestic sectors and prevent leakage effects associated with the expansion of unregulated sectors in other countries. One means of achieving this is through border tax adjustments (BTAs) which are tariffs on emissions embodied in imports coming from countries which are not controlling their emissions. While BTAs may be an attractive option for countries wishing to pursue unilateral mitigation policies, there are some significant challenges would need to be overcome before they could be implemented. One of the main difficulties is to measure the emissions that embodied in imports. Moreover, even if this could be done, it is not clear whether such import tariffs would be permitted under the provisions of the World Trade Organization (WTO). Consequently, there is the risk that there application would lead to retaliation by trading partners, leading to welfare losses from international trade distortions (Key and Tallard 2011). One potential solution for implementing countries is to tax imports at the same rate as their domestic products. While the failure to account for differences in emission intensities would introduce economic inefficiencies, the instrument would at least be consistent with WTO provisions (Key and Tallard 2011).

Recent studies have investigated the effects of BTAs on emissions leakage, welfare and competitiveness under different climate change policy scenarios (Burniaux et al. (2010), Winchester (2011), Hubler (2011), Monjon and Quirion (2011), Weitzel and Peterson (2011), Seymore et al. (2011), Zhou et al. (2011)). Most of these studies have focused on CO_2 combustion emissions from manufacturing sectors. The overall conclusion from the literature is that effectiveness of BTAs is quite heterogeneous. The size of the BTA-implementing countries, the number of countries in a coalition, suppliers' response to a BTA, and the method of implementation are listed as a few of the determinants of the effectiveness of BTAs. This heterogeneity suggests that additional studies may be required to assess the effectiveness of BTAs in the context of other sectors and other types of GHG emissions.

The role of BTAs in the context of agriculture has received less attention compared with manufacturing sectors. While agriculture plays a small role in CO_2 combustion emissions, it is much more important in the context of the hitherto under-emphasized, non-CO_2 emissions, including methane and nitrous oxide. By drawing on recent research into non-CO_2 emissions and abatement possibilities in global agricultural sectors, this paper seeks to complement and extend the existing literature on BTAs. This study builds on an extended version of the GTAP-AEZ-GHG model which is documented in Golub et al. (2009). The focus of the BTA analysis presented here is primary and processing livestock sectors (see Appendix Tables A1 and A2 for region and sector aggregation) which have been shown to have high emissions intensities which vary greatly across regions (Avetisyan, et al., 2011).

The experimental design of the study follows Burniaux et al. (2010). The effects of BTAs on emission leakage, welfare, and competitiveness are assessed in two regional configurations: first with the EU operating alone and secondly, considering the Annex I region as a whole. Four scenarios are considered: in the first two scenarios (*EU noBTA* and *Annex1 noBTA*), the EU alone and Annex I as a whole, respectively, impose 27$/t$CO_2$eq GHG emissions tax on all sectors and provide 27$/t$CO_2$eq carbon sequestration incentive to forest producers. In the last two scenarios (*EU BTA* and *Annex1 BTA*), in addition to the GHG emission tax and forest carbon sequestration incentive, BTAs are introduced by EU and Annex I countries, respectively, on all commodities imported from non-abating regions. (See Appendix Table A3 for a summary of our scenarios.)

We find that unilateral imposition of an emissions tax dramatically changes the pattern of livestock sectors competitiveness at the global scale. However, the BTAs relieve the burden of emission taxation on the implementing regions' net exports of livestock products, in both *Annex I* and *EU27* scenarios. In *Annex I* scenario, emissions leakage through the primary livestock sectors is 47%. BTAs reduce this rate to -14%, which means that emissions in non-Annex I livestock sectors are also reduced under the BTA. In *EU27* scenario, on the other hand, 54% emissions leakage in the primary livestock sectors declines to -53%. BTAs are also shown to be more in relieving the burden of the emission tax for Annex I livestock sectors than for Annex I cropping sectors. Considering all sectors in our analysis reveals that, in contrast to other studies (Burniaux et al., 2010; Hubler, 2011; Weitzel and Peterson, 2011), BTAs are very effective in reducing emission leakage. However, similar to Burniaux et al. (2010) effectiveness of BTAs is reduced with increases in coalition size. Whereas BTAs are capable of fully eliminating emission leakage when only EU27 abate their emissions, this is not the case for the Annex I BTA. The rest of this paper proceeds as follows. Section 2 introduces the model used in this study. Section 3 describes method to calculate emissions associated with production of a good. Section 4 presents the scenarios and results focusing on the effects of BTAs. Section 5 discusses sensitivity analysis of main results. Section 6 concludes.

2 The Model

This study builds on a global computable general equilibrium model GTAP-AEZ-GHG documented in Golub et al. (2009). This is an integrated framework that links the agricultural, forestry, food processing and other sectors through land, and other factor markets and international trade, and incorporates different land-types, land uses and related GHG emissions and sequestration. The model draws on a detailed non-CO_2 GHG emissions database by Rose et al. (2008), specifically designed for use in global economic models. The database provides highly disaggregated emissions information and is mapped directly to countries, economic sectors and drivers (Rose and Lee, 2009). The model also incorporates mitigation cost curves for different regions and sectors based on data from the USEPA (USEPA, 2006) by calibrating relevant parameters in the GTAP-AEZ-GHG model to these curves. The forestry component of the model is calibrated to the results of the state of the art partial equilibrium global forestry model documented in Sohngen and Mendelson (2007). Forest extensification and intensification decisions are modeled separately to better isolate the land competition between agriculture and timber products.

Important extensions of the model for this paper include: (1) updating the global economic data for the model from 2001 to 2004; (2) increasing the number of global regions from 3 to 19 (see Table A2); (3) disaggregation of regional ruminant livestock sectors into ruminant meat and dairy; (4) calibration of the agricultural sectors of the model to disaggregated marginal abatement cost curves (MACs) that correspond to the new model region and sector structure; (5) updating forest carbon sequestration supply curves using a new forestry model that conforms to the regions, AEZ structure and land supply structure of the CGE model. Finally, (6) the model covers carbon dioxide (CO_2) emissions from fossil fuel combustion in addition to the methane (CH_4), nitrous oxide (N_2O), fluorinated gases (F-gases) emissions and forest carbon stock data that were used in earlier work.

Unlike other studies on BTA analysis (Burniaux et al. (2010), Winchester (2011), Hubler (2011), Monjon and Quirion (2011), Weitzel and Peterson (2011), Seymore et al. (2011), Zhou et al. (2011)) we do not aim to achieve a specific regional emissions reduction, since we are focusing on the outcome in just a few sectors. Instead, we exogenously set the carbon price at 27$/t$CO_2$eq and investigate the effects of the illustrative abatement policy on leakage and competitiveness in livestock, agricultural and other sectors. Emissions in agriculture are distinguished not only by sector of origin, but also driver (e.g., nitrous oxide emissions from coarse grains production are tied to fertilizer applications; methane emissions from paddy rice production are tied to land). Other features that differentiate this study from other BTA analyses include the incorporation of the forest carbon sequestration and explicit competition for land between agriculture and forests, and very detailed representation of emissions and abatement options in agriculture.

3 Method to Calculate Emissions

There are two methods to calculate emissions associated with the production of a good. A simple method includes only direct emissions from production processes. More complicated methods include total direct and indirect emissions. The method used in this study takes into account both direct and indirect emissions. Using livestock sectors as an example, total emissions from primary livestock production are calculated taking into account direct emissions from livestock farming and manure management, as well as indirect emissions from producing feed for animals, emissions from growing crops to produce the feed and so on. In addition to these emissions, processed livestock products also embody additional emissions from processing and transportation.

A convenient way to estimate these emissions is to run our global model as a quantity-based, global input-output model in which all prices are fixed at their baseline level and output is simply doubled. With fixed prices, no substitution will occur, and to double the production of that sector we must double input use in the sector. This will trigger increases in the production of those inputs, and associated emissions. Of course this rise in inputs will not be by the full 100% unless the expanding sector is the only user of these inputs. Furthermore, the input supply sectors must also expand their purchases, thereby leading to further rounds of emissions, and so on. By solving the entire model at once we are able to capture all of these direct and indirect changes in emissions. This calculation was conducted for all 29 sectors of the model to obtain total sector emissions for each region in the model.[1]

Table 1 reports regional total, direct and indirect, emissions from three primary and three processing livestock sectors. The ruminant meat sector (before processing) is responsible for 2,593 $MtCO_2eq$ (95% direct emissions). Adding 854 from primary non-ruminants (64% direct emissions) and 667 from dairy production results in total 4,115 $MtCO_2eq$ emissions from the global primary livestock production. Adding 890 $MtCO_2eq$ from livestock processing sectors results in total 5,005 $MtCO_2eq$ emissions from the global livestock supply chain.[2]

< insert Table 1 here >

Table 2 reports that total emissions from cropping sectors amount to 2,824 $MtCO_2eq$. Other agricultural activities (OthAgri) and paddy rice production are the two leading emitters among cropping sectors responsible for 1,213 $MtCO_2eq$ and 819 $MtCO_2eq$, respectively. Paddy rice in China and Rest of Southeast Asia (R_SE_Asia) are the two leading contributors among all cropping sectors and regions emitting 278 and 155 $MtCO_2eq$, respectively.

< insert Table 2 here >

The final step needed for BTA implementation is to calculate emissions embodied in imported goods. An appropriate portion of the total sector emissions obtained with the method described above is assigned to exports of product *i* from region *s* to *r*, based on the share of the bilateral exports in total region *s* output of the product in question.

[1] Because of the use of imported intermediates by each sector in each of 19 regions of the model, this exercise should be repeated 19 times to obtain region specific direct plus indirect emissions from the considered sector. And for the analysis of all 29 sectors, simulation should be repeated 19x29 times, in total. To save on computing time, for each sector the calculation was done only once for all regions together. Table A4 demonstrates that for processed non ruminant sector calculating total emissions for all regions together does not yield significantly different results from those obtained by calculating total emissions region by region. We assume this finding holds for all other sectors, and for the BTA analysis employ emissions calculated from first, computationally faster, method.

[2] The emissions from processing sectors represent only additional to primary sectors emissions and do not include emissions from livestock farming and all other emissions already counted in the emissions from primary livestock sectors.

4 Scenarios and Results

GHG mitigation policy implemented by Annex I

The impacts of the 27$/t$CO_2$Eq Annex I emission tax and forest carbon sequestration subsidy on all sectors without and with BTAs reported in Figures 1a-c. Figures 1a and 1b show the percentage changes in GHG emissions and output for the livestock sectors in the two scenarios, respectively. Overall, non-Annex I livestock emissions and production expand in the absence of BTAs. With BTAs, the picture is reversed in Brazil, Other South America and Sub Saharan Africa. BTAs reverse output reductions in EU27 and Other Europe (Oth_Europe) primary and processed ruminant sectors, and primary and processed dairy in Japan, but do not reverse negative impact of the GHG mitigation on livestock output in USA, Oceania and Canada, though livestock output reductions in these regions are smaller under BTAs. Figure 1c reports the changes in trade balances by livestock sector and region in both simulations. The figure shows that while the emission tax in Annex I dramatically changes the pattern of global competitiveness, BTAs implemented by the Annex I are indeed helpful to reduce or eliminate negative impact of emission tax on livestock sectors net exports in all Annex I regions (except Oceania).

< insert Figures 1a-c here >

The emissions leakage rate is defined as the ratio of additional GHG emissions in non-abating regions (non-Annex I countries in *Annex1* scenario) to the emission reduction achieved by the abating countries (Annex I countries in *Annex1* scenario). Table 3 presents the emissions leakage at $27/t$CO_2$-eq carbon price with and without BTA cases. Results show that BTAs eliminate emissions leakage in livestock and limit it in all other sectors. Without BTAs, leakage through dairy, ruminant and non-ruminant sectors is 47%. Decomposition of leakage rate in livestock sectors by sectors shows that among the regions, China and Sub Saharan Africa are the main source of leakage contributing 11% and 9.6%, respectively. Among the primary livestock sectors, the ruminants sector is by far main source of leakage contributing 44% (see Figure 2a). BTAs reduce emissions leakage rate in primary livestock sectors down to -14%, which means that emissions in non-Annex I livestock sectors are also reduced under BTAs. With BTAs, imports from non-Annex I become more expensive and Annex I demand for these products falls, which in turn leads to reduction in non-Annex I output and emissions Although, BTAs do not have the reverse leakage effect on cropping sectors, they are still powerful enough to make remarkable impacts on the leakage rate in those sectors. Namely, emission leakage in non-Annex I cropping sectors decrease from 16% to 5%. Finally, BTAs reduce economy–wide emissions leakage from 11% to 2%.

< insert Table 3 here >

< insert Figure 2a here >

Table 4 summarizes the percentage changes in output, emissions, and emission intensities for different sectors according to their location in either Annex I or non-Annex I regions for scenarios *Annex1 noBTA* and *Annex1 BTA*. In both scenarios, global emission intensities are reduced as emissions fall by more than output. In the BTAs scenario, global emission intensities fall more as imports from non-Annex I become less competitive in Annex I market, and non-Annex I production and emissions shrink.

< insert Table 4 here >

GHG mitigation policy implemented by EU27

In addition to our analysis of the impacts of BTAs implemented by Annex 1 regions against non-Annex 1 regions, we also analyze the EU only case: we investigate effectiveness of BTAs implemented by EU27 regions against non-EU regions. Such analysis is important because the EU is seriously considering the use of BTAs. The analysis also allows us to compare our results with Burniaux et al. (2010) study. In this section, two scenarios are considered. In the first scenario, EU27 regions impose 27\$/tCO_2eq GHG emissions tax on all sectors and pay 27\$/tCO_2eq carbon sequestration subsidy to domestic forestry sector. In the second scenario, in addition to the domestic emissions tax and sequestration subsidy, EU27 regions introduce boarder tax adjustments on all imports from non-EU27 regions.

Results of the 27\$/tCO_2eq EU27 emissions tax and forest carbon sequestration subsidy without and with BTAs are reported in Figures 3a-c. Figures 3a and 3b show the percentage changes in GHG emissions and output for the livestock sectors in the two scenarios. As with the Annex I scenario, livestock production and emissions in untaxed regions expand in the absence of BTAs. With BTAs, the picture is reversed in Brazil, Other South America, Sub Saharan Africa and Oceania. Neither the EU27's GHG mitigation policy nor BTA implementation seems to affect USA's production and emission profiles for the livestock sectors. BTAs are helpful in supporting livestock output in EU27: the contraction of dairy and non-ruminant sectors declines with BTAs, and there is even an increase in the processed and unprocessed ruminant sectors. Figure 3c reports the changes in trade balances by livestock sector and region for both simulations. The figure shows that BTAs implemented by the EU27 are helpful to relieve the burden of emissions tax on the EU27 livestock sectors net exports, except processed dairy.

< insert Figures 3a-c here >

Table 3 shows that as with the Annex I scenarios, BTAs implemented by the EU eliminate emission leakage in livestock sectors and limit leakage in cropping and all other sectors. Without BTAs, leakage through dairy, ruminant and non-ruminant sectors is 54%. Decomposition of the leakage rate in primary livestock sectors by regions and by sectors shows that among the regions, Sub Saharan Africa, Brazil and Oceania are the main regions of leakage contributing 14%, 10%, and 7% respectively. Among the primary livestock sectors, the ruminants sector is by far main source of leakage contributing 50% (see Figure 2b). With inclusion of BTAs, GHG emissions in farm livestock sectors of non-EU27 is reduced by 0.8% which is due to output reduction triggered by reduction in EU demand for imports. Grubb *et al.*, 2002; Gerlagh and Kuik, 2007) suggest that the main source of reverse leakage is likely to be endogenous technological change and international technology spillovers to non-mitigating countries. The source of reverse leakage in our study, on the other hand, is the decrease in demand for EU imports from non-EU regions due to import price increase with BTAs. Unlike the Annex I scenarios, BTAs eliminate emissions leakage in cropping and all other sectors. In cropping sectors, BTAs lead to a reduction in emissions leakage from 16% to -15%. For all sectors, BTAs reduce emission leakage from 19% to -4%. As an overall conclusion, this analysis shows that BTAs implemented by the EU are effective tool in controlling emission leakage in both the livestock sector and the overall economy. Table 5 summarizes the percentage changes in output, emissions, and emission intensities for different sectors, according to their location in either EU27 or non-EU27 regions for scenarios *EU noBTA* and *EU BTA.*

< insert Figure 2b here >

< insert Table 5 here >

Coalition size and effectiveness of BTAs

In this section, the four scenarios separately analyzed in previous two sections are brought together to investigate the relationship between effectiveness of the BTAs and the coalition size. The findings of this study are then compared to results reported in Burniaux, Chateau, and Duval (2010). In their study, the authors focus on energy intensive-industries and analyze effects of BTAs on emissions leakage, welfare, and competitiveness when the EU alone or when Annex I as a whole abate their emissions by 20% by 2020 relative to 2005 levels. Table 6 is a replica of Table 2 in Burniaux et al. (2010) incorporating our findings alongside the earlier ones. According to Burniaux's et al. (2010) results, leakage rates in scenarios *EU noBTA* and *Annex I noBTA* are 3.8% and 4.4%, respectively. However, corresponding rates in our analysis are 19% and 11%, respectively.

< insert Table 6 here >

Like Burniaux et al. (2010), our results show that BTAs are very effective in reducing emission leakage but their effectiveness reduces as coalition size increases. BTAs are capable to fully eliminate emission leakage when only EU27 regions abate their emissions: emission leakage reduces from 19% to -4%. However, when coalition expands from EU27 to Annex 1, BTAs cannot fully eliminate leakage: they can only reduce it from 11% to 2%. Following Burniaux et al. (2010), welfare impacts of abatement policy and BTAs are measured by Hicksian equivalent variation in income. Table 6 shows that the increase in the welfare loss with the coalition size is not as much as Burniaux et al.'s (2010) findings. In Burniaux et al. (2010), global welfare loss due to the abatement policy increases six-fold from 0.1% to 0.6% as the coalition expands from EU to Annex 1. In our study, however the global welfare loss increases only two-fold from 0.1% to only 0.2% with the coalition size. This is an expected result considering the major difference between the two studies that the emissions price is fixed at 27\$/tCO_2eq in our study while it is endogenous and varying between 20\$/tCO_2eq and 43\$/tCO_2eq in Burniaux et al. (2010) study (see Table 6). Clearly, the larger tax, the larger is associated welfare loss.

Burniaux et al. described two channels of carbon leakage: international trade, and fossil fuel price. International trade related leakage occurs as emission-intensive sectors in abating regions lose their market shares because of abatement policies to their rivals in non-abating regions. Fossil-fuel price related carbon leakage occurs as carbon taxes in abating regions reduce domestic demand for fossil fuels and price of fossil fuel in global markets which leads to greater fossil foul use and hence higher GHG emissions in non-abating regions. Therefore, Burniaux et al. explain this negative relationship between effectiveness of BTAs on leakage and coalition size by (1) under smaller coalitions, carbon leakage mostly occurs because of the international trade channel rather than the fossil fuel price channel; and (2) BTAs address the former but not the latter channel.

In our analysis, when we decompose emission leakage, we find that, the nature of emission leakage does change over the coalition size (see Figure 4). In scenario *EU noBTA*, 19% carbon leakage is decomposed into 14% international trade channel and 5% fossil fuel price channel. In scenario *Annex1 noBTA*, 11% total carbon leakage is decomposed into 7%

international trade channel and 5% fossil fuel price channel (See column "All Sector" in Table 7). The contribution of the fossil fuel price channel to carbon leakage increases in absolute terms with coalition size, but is stable relative to the abatement target (it is about 5% in both EU and Annex I mitigation scenarios). The international trade channel remains the main channel of carbon leakage in our analysis as the coalition is expanded from EU to Annex I. However, relative contribution of the international trade channel is reduced as the coalition expands. Thus we find support for the Burniaux et al.'s (2010) observation that under smaller coalitions, carbon leakage mostly occurs because of the international trade channel rather than the fossil fuel price channel.

< insert Figure 4 here >

Further, in *EU BTA* scenario, the leakage rate is eliminated completely and in *Annex I BTA* leakage rate is reduced from 11% to 2%. Decomposition of the leakage rates in those scenarios shows that BTAs reduce leakage through the international trade channel (negative blue bars) while leakage through fossil fuel prices is unaffected in *Annex I BTA* scenario and even increases in *EU BTA*. Overall, we find a negative relationship between effectiveness of BTAs and coalition size, and our results support Burniaux et al.'s (2010) explanation for this negative relationship.

< insert Table 7 here >

5 Sensitivity Analysis

In our model, it is assumed that commodities are differentiated according to their origin (Armington, 1969). Therefore, leakage rates are particularly sensitive to the values of Armington elasticities of substitution amongst imports from different sources. The size of non-energy market related leakage is represented by the Armington elasticities. In this study, they are taken from the GTAP 6.2 database. Results of the sensitivity analysis with respect to the Armington elasticities are presented in Table 8. The first panel of results is the leakage rates in different sectoral groups for each scenario with the initial Armington elasticities[3]. The second (third) panel of results is the leakage rates in the same sectoral groups and scenarios when the Armington elasticities for all trade commodities are higher (lower) than their original values.[4]

< insert Table 8 here >

Our overall sensitivity analysis shows that our results on the effectiveness of BTAs on emissions leakage are robust to alternative values of Armington elasticities. As expected, leakage rates increase with increases in the Armington elasticities. As imported products become closer substitutes for the domestic goods, unilateral abatement policy implemented in the home country results in switch in the demand from domestic to imported product, expansion of production in non-participating countries, and increase in emission leakage. On the other hand, as domestic and imported products are less substitutable, the leakage rates are limited. In our results, as the Armington elasticities for all trade commodities decrease by 70%, the leakage rate in primary livestock sectors decreases from 47% to 12% in *Annex I noBTA* scenario and from 54% to 14%

[3] The same results as given in Table 3.

[4] In other case, following Burniaux et al. (2010), the Armington elasticities only for manufacturing commodities are changed. Leakage rates in those cases are represented in the fourth and fifth panels in Table 8.

in *EU noBTA* scenario. Similarly, the leakage rate in cropping sectors decreases from 16% to 5% in *Annex I noBTA* scenario and from 16% to 3% in *EU noBTA* scenario. Our results also reveal that BTAs become less effective at reducing emission leakage as the Armington elasticities increase. In the *Annex1 noBTA* scenario, while emissions leakage rate decreases from 47% to -14% with BTAs in original Armington elasticities case, it decreases from 75% to -6% with BTAs when Armington elasticities for all trade goods are increased by 80%. On the other hand, in the same scenario, under 70% reduction in Armington elasticities for all trade goods, emission leakage rate decreases from 12% to 24% when BTAs are implemented.

6 Conclusions

As the UNFCCC Conference of the Parties (COP) negotiations have thus far failed to secure an extension of the Kyoto Protocol beyond 2012, there is growing momentum for unilateral GHG emissions mitigation policies which should satisfy two conditions: (1) do not cause the home country to lose its market shares in the global markets; (2) do not cause any significant carbon leakage in global emissions. By design, simple GHG emissions abatement policies cannot satisfy these conditions and hence additional mechanisms are required such as Border Tax Adjustments (BTAs). They allow individual countries or cohorts of countries to pursue unilateral market-based policies without harming their competitiveness while reducing the risks of leakage.

It is quite popular in the literature to measure the effectiveness of BTAs at competitiveness and leakage issues for manufacturing sectors under various abatement scenarios. However, to our knowledge there is no study making similar investigation in livestock sectors. Considering the fact that those sectors are the significant sources of non-CO_2 emissions, understanding performance of BTAs in controlling competitiveness and emission leakage for those sectors is important. Therefore, the main goal of this paper is to fill this gap in the literature by assessing the impacts of BTAs on competitiveness and emissions leakage in livestock sectors under different abatement scenarios.

Our results indicate that BTAs are quite an effective tool for controlling emissions leakage in livestock and other sectors. Further, in some case these tools can even reverse emissions leakage. Decomposition of leakage rate by regions shows that in both *Annex1 noBTA* and *EU27noBTA* scenarios the ruminants sector is by far main source of leakage among the primary livestock sectors. In *Annex1 noBTA* scenario, decomposition of leakage rate in livestock sectors by sectors shows that among the regions, China and Sub Saharan Africa are the main source of leakage. In *EU noBTA* scenario, decomposition of the leakage rate in primary livestock sectors shows that among the regions, Sub Saharan Africa, Brazil and Oceania are the main regions of leakage contributing.

Consistent with Burniaux’s et al. (2010) findings, we find that power of BTAs decreases with the coalition size, i.e., as the number of regions in a coalition for controlling their emissions increases effectiveness of BTAs at limiting emission leakage declines. Decomposition of the leakage rates in our scenarios shows that BTAs reduce leakage through the international trade channel while leakage through fossil fuel prices is unaffected in *Annex I BTA* scenario and even increases in *EU BTA*.

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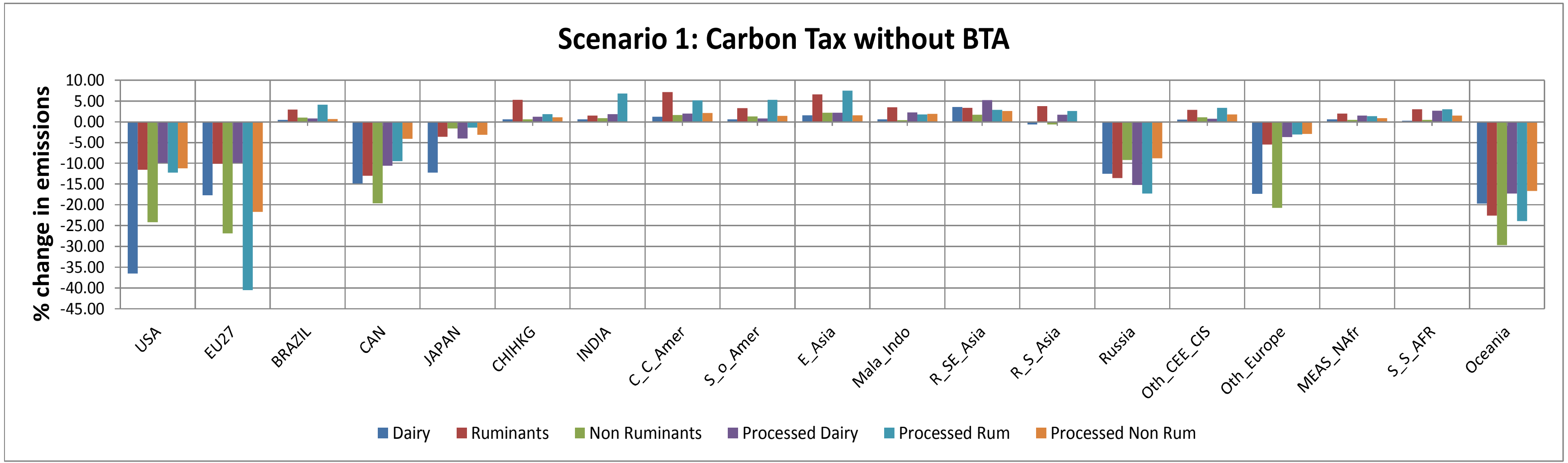
Figure 1a - Changes in emissions from livestock sectors under 27$/t$CO_2$eq carbon tax on all sectors and sequestration subsidy in Annex 1, without and with BTAs (%)



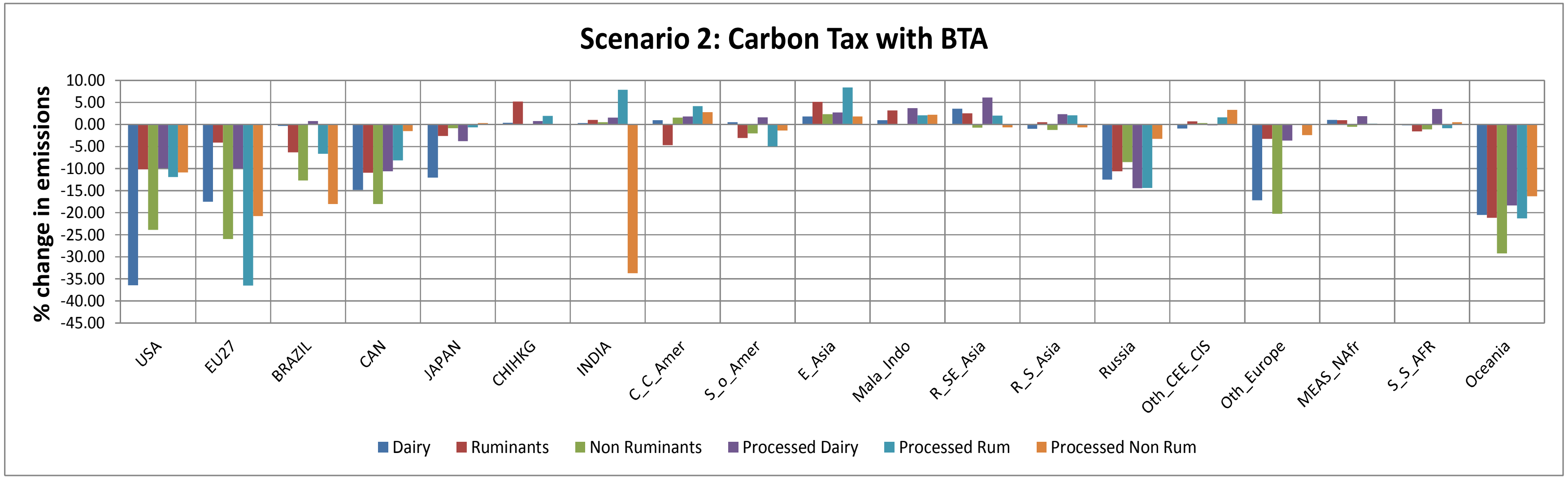
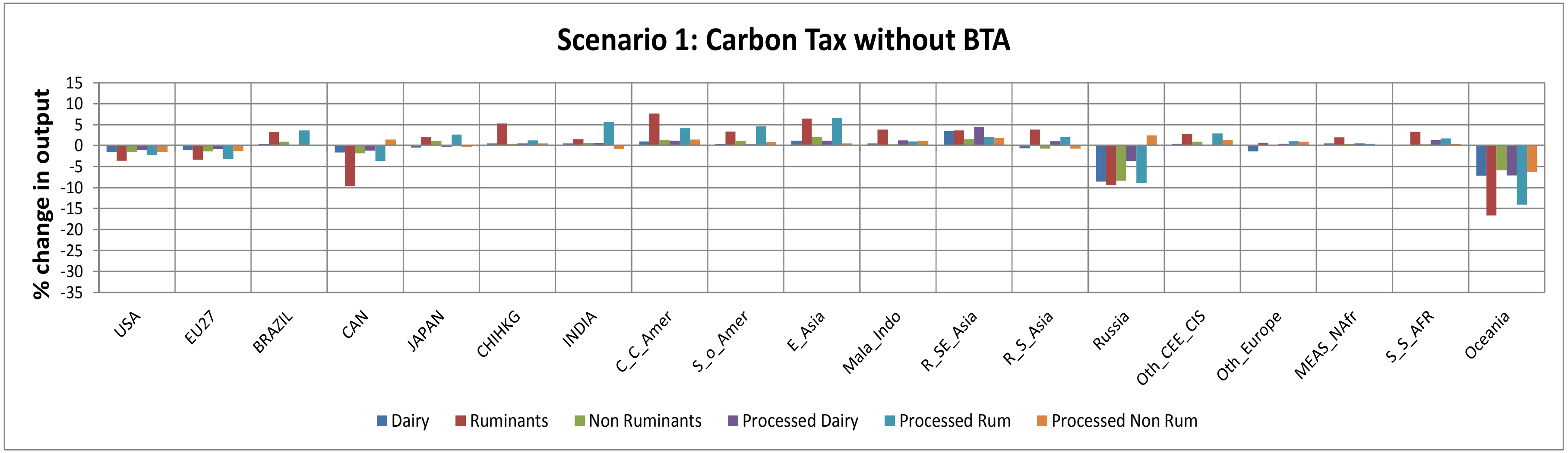


Figure 1b - Changes in livestock sector output under 27$/t$CO_2$eq carbon tax on all sectors and sequestration subsidy in Annex 1, without and with BTAs (%)



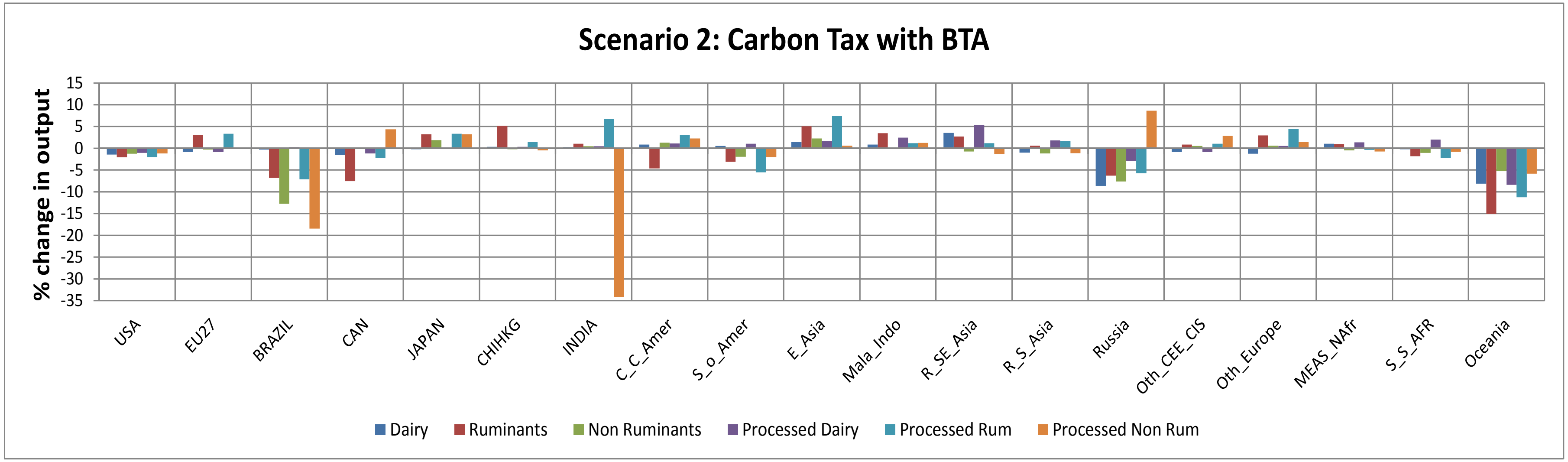
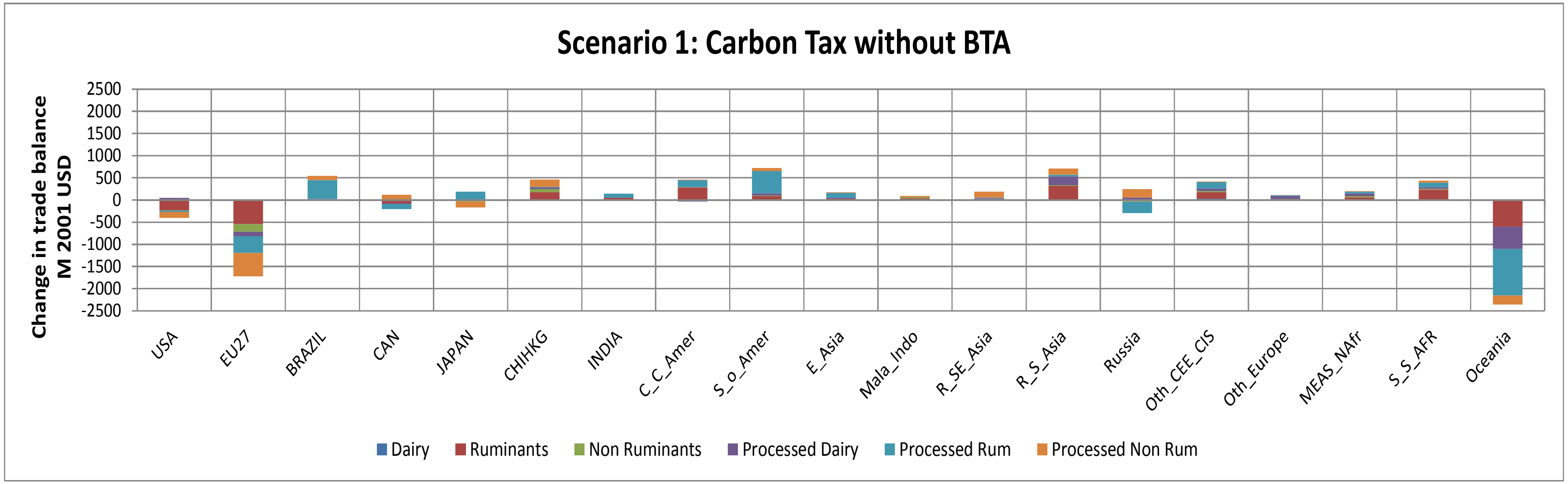


Figure 1c - Changes in livestock sector trade balances under 27$/t$CO_2$eq carbon tax on all sectors and sequestration subsidy in Annex 1, without and with BTAs, by sector and region (mill 2001 USD)



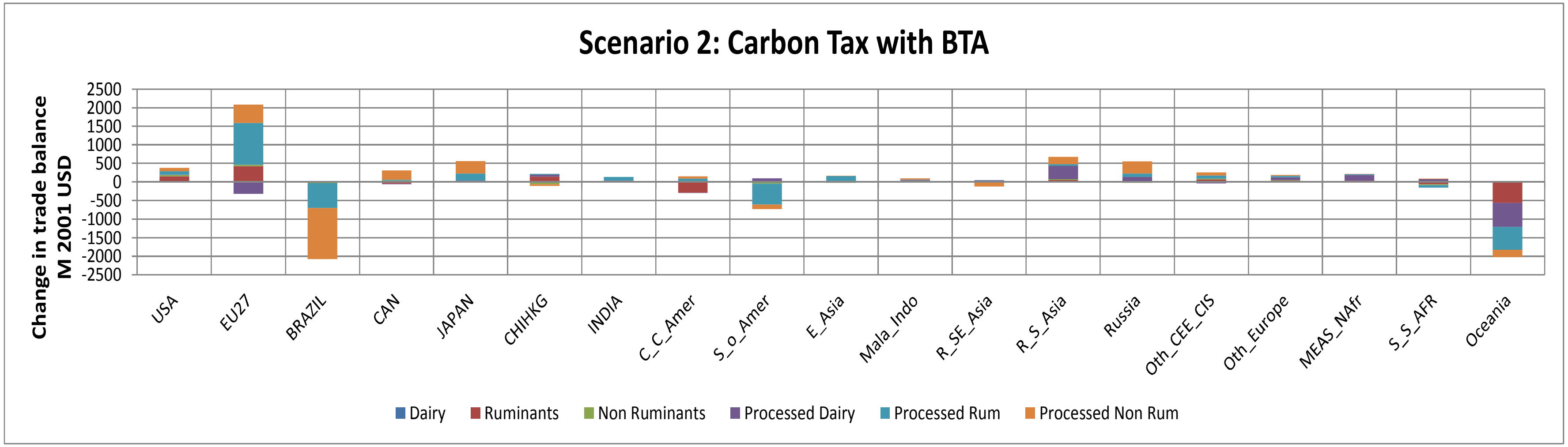


Figure 2a – Decomposition of 47% Leakage Rate in Primary Livestock Sectors in *Annex I noBTA* scenario by sectors and regions

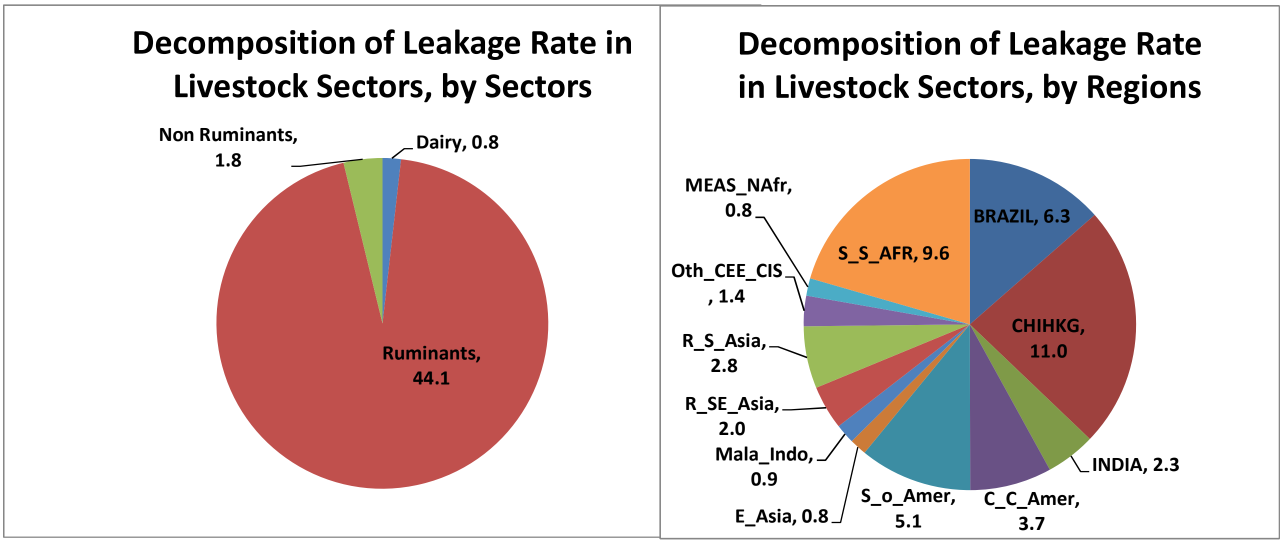


Figure 2b – Decomposition of 54% Leakage Rate in Primary Livestock Sectors in *EU noBTA* scenario by sectors and regions

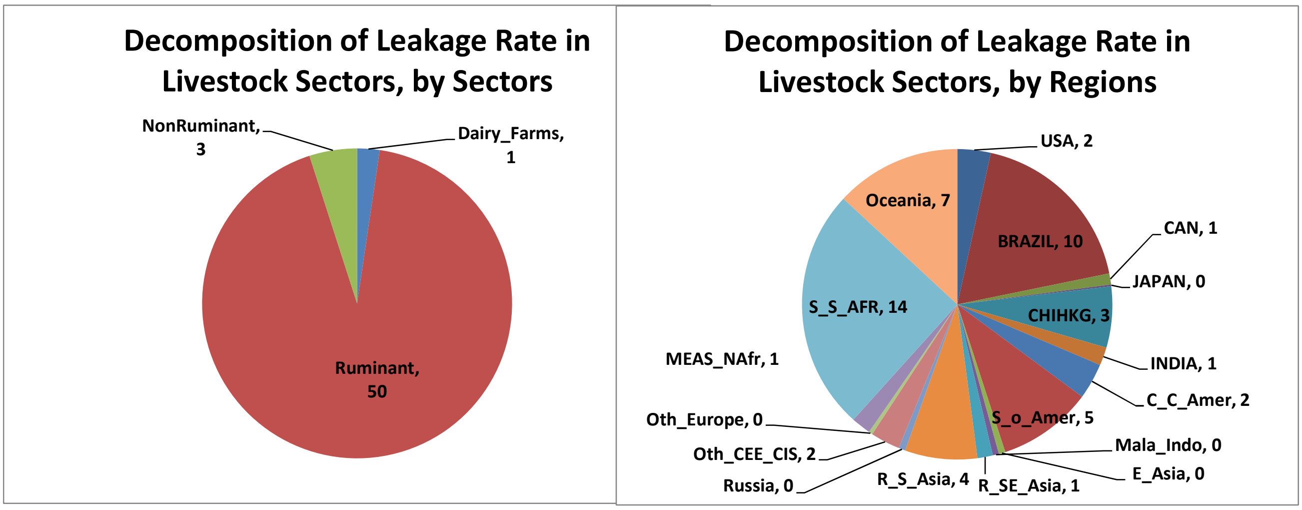
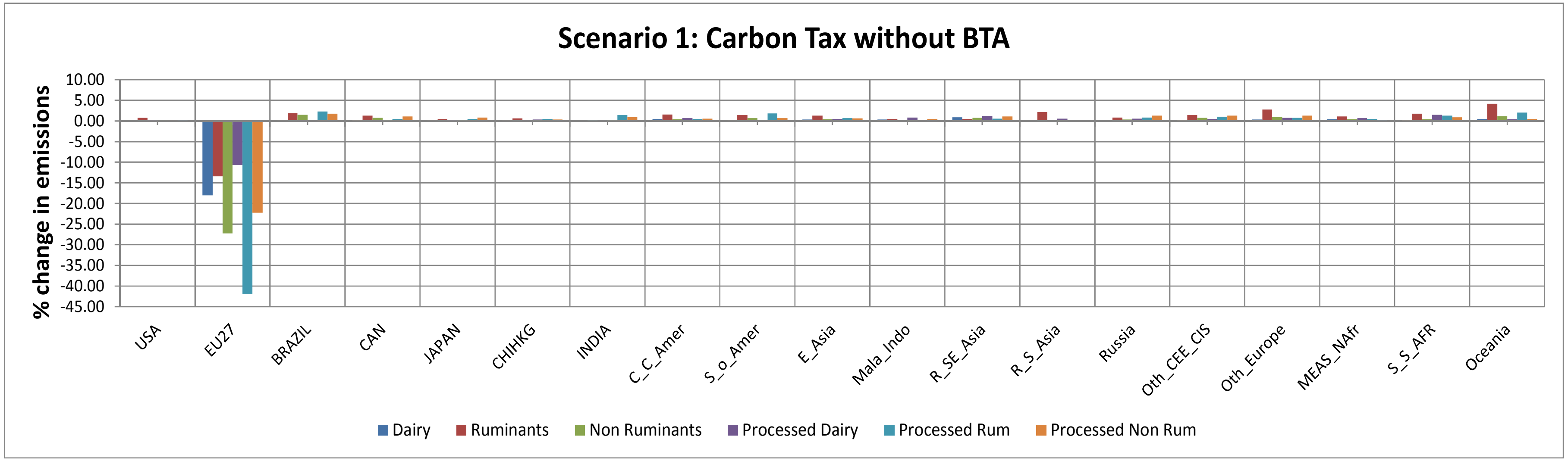


Figure 3a - Changes in direct emissions from livestock sectors under 27$/t$CO_2$eq carbon tax on all sectors and sequestration subsidy in EU, without and with BTAs (%)



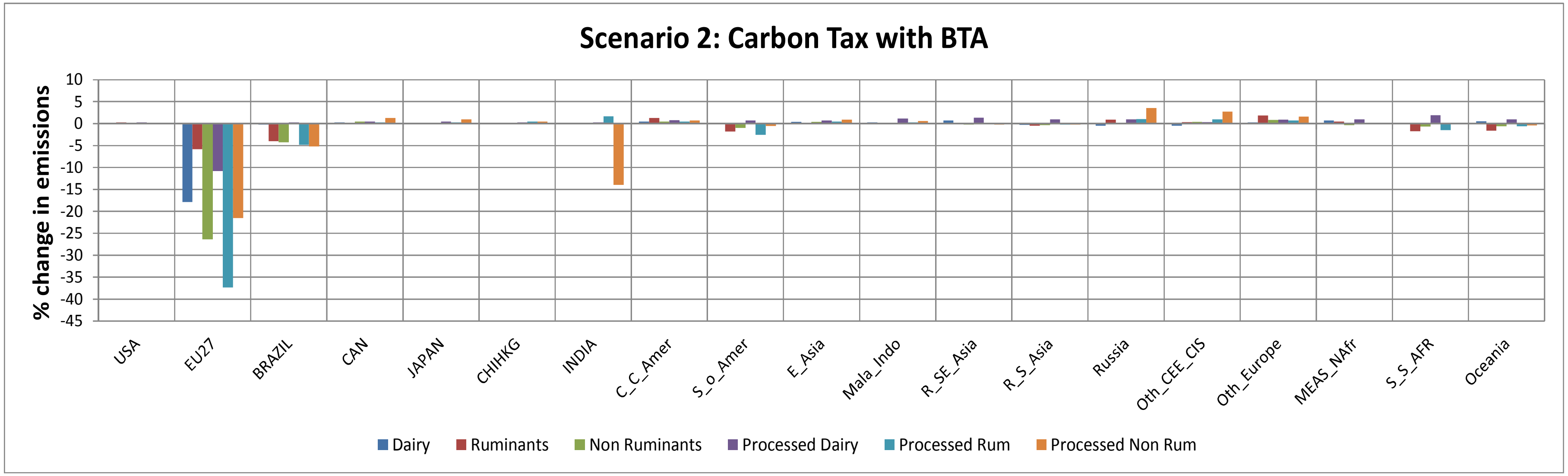


Figure 3b - Changes in livestock sector output under 27$/t$CO_2$eq carbon tax on all sectors and sequestration subsidy in EU, without and with BTAs (%)

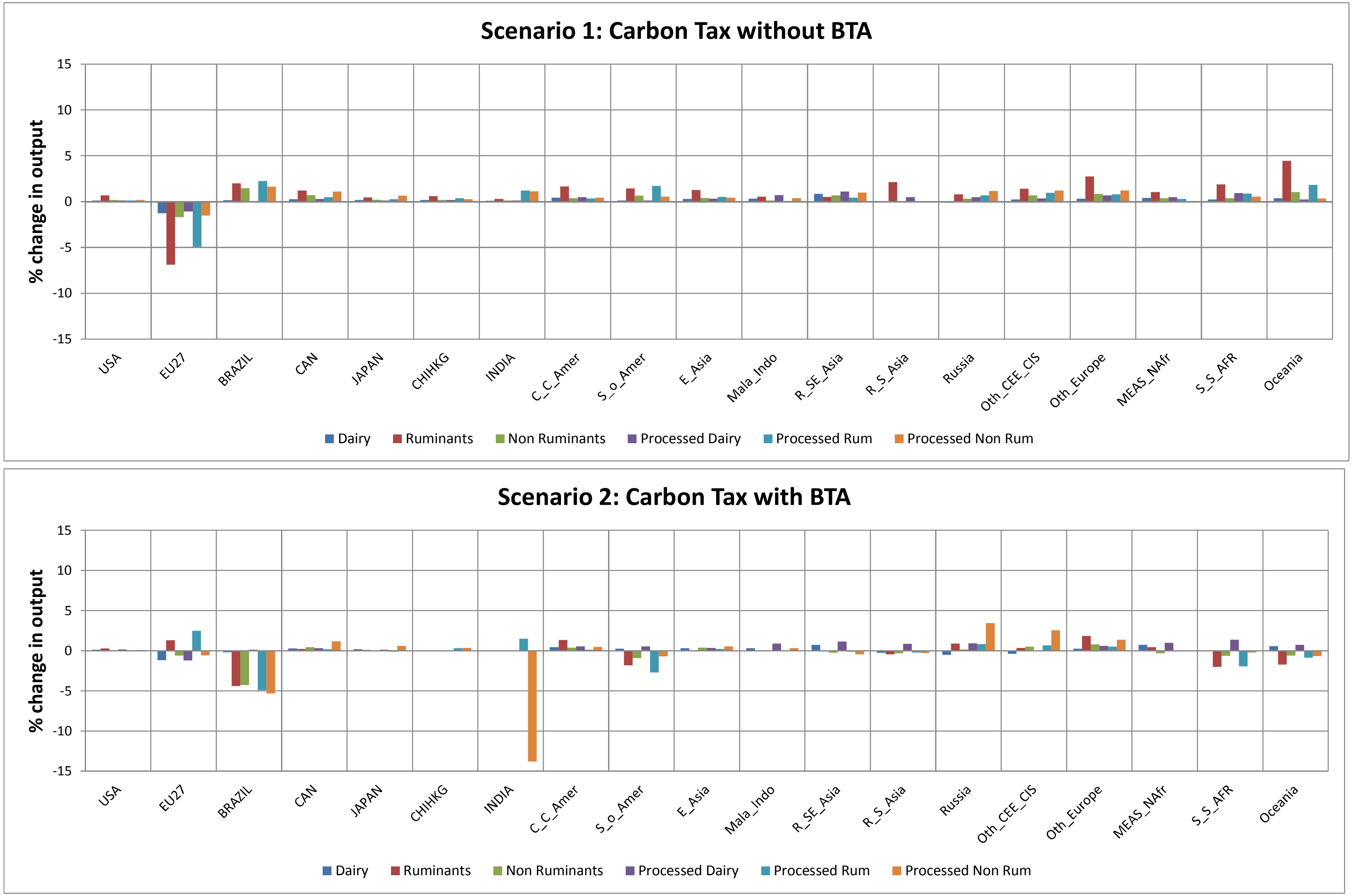
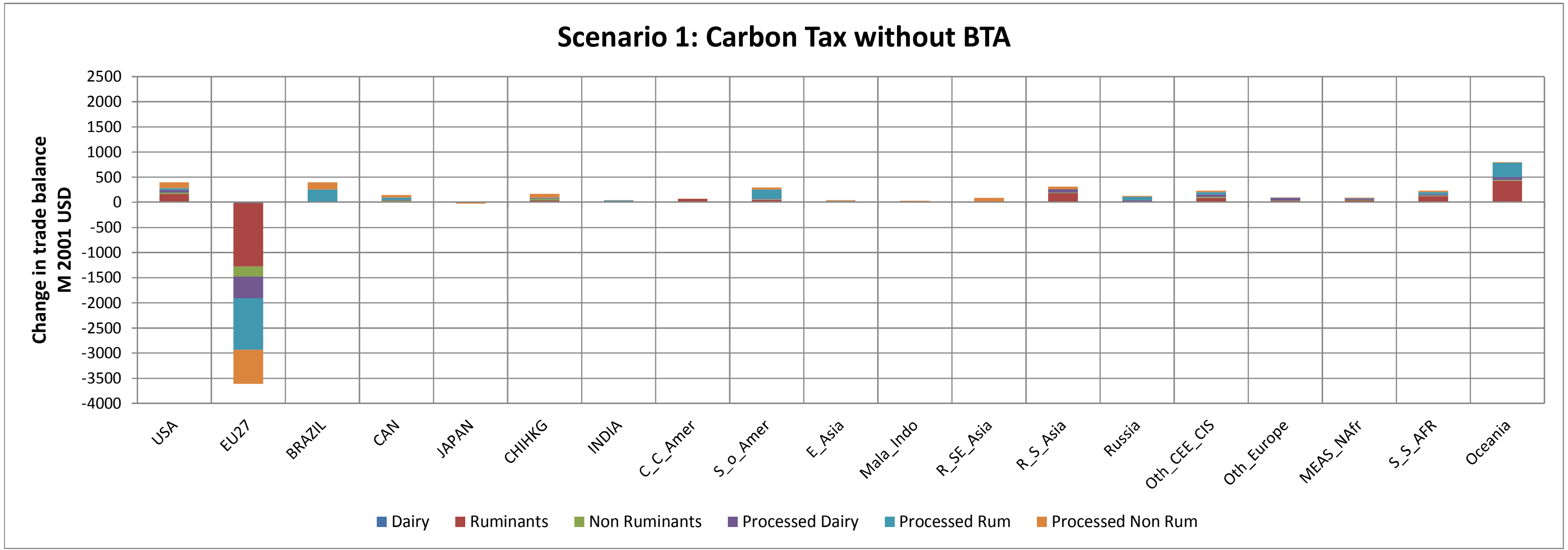


Figure 3c - Changes in livestock sector trade balances under 27$/t$CO_2$eq carbon tax on all sectors and sequestration subsidy in EU, without and with BTAs, by sector and region (mill 2001 USD)



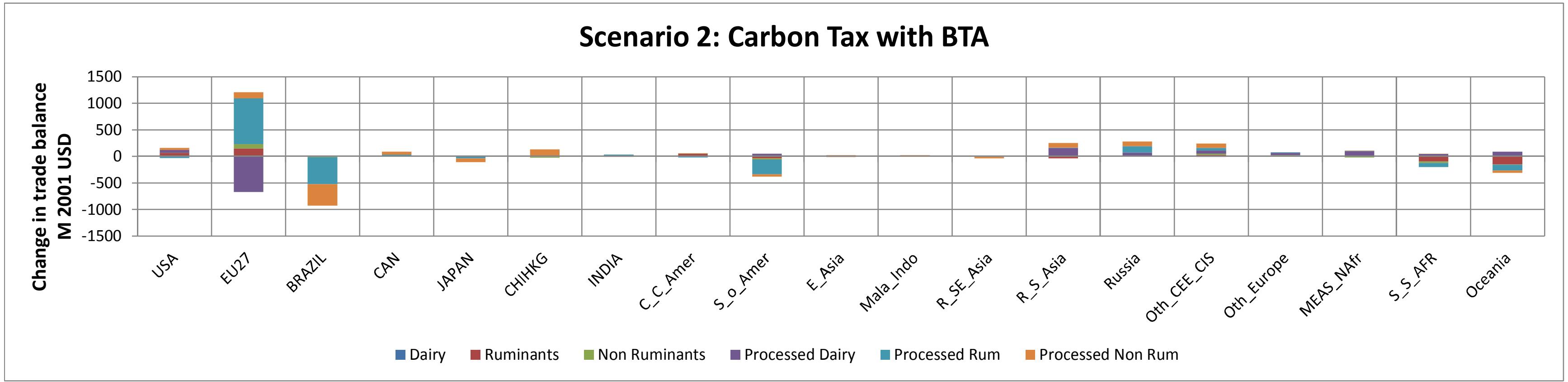


Figure 4 – Decomposition of leakage rate in all sectors to international trade-channel and fossil fuel price-channel, under 27$/t$CO_2$eq carbon tax on all sectors and sequestration subsidy

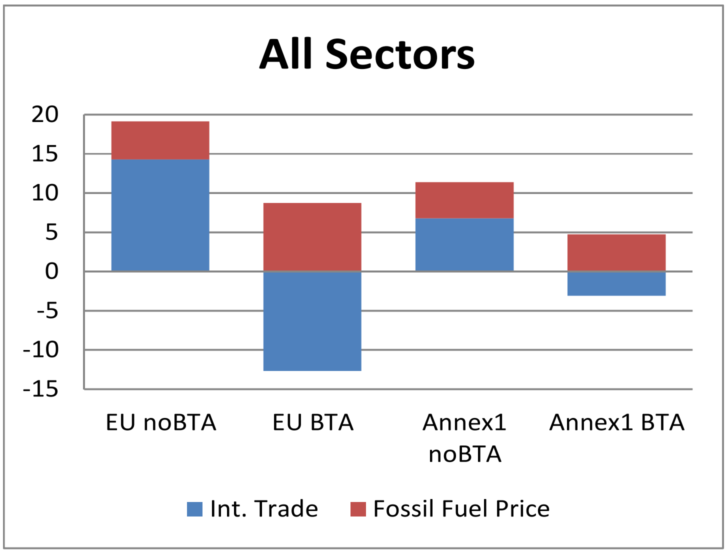


Table 1 – Direct and indirect emissions from primary and processing livestock sectors ($MtCO_2eq$)

	Dairy	Ruminant	Non Ruminant	Processed Dairy	Processed Rum	Processed NonRum
USA	88	171	85	60	56	59
EU27	129	173	108	56	17	72
BRAZIL	40	324	33	8	11	35
CAN	11	31	11	8	7	5
JAPAN	7	7	11	4	8	2
CHIHKG	18	318	347	34	8	52
INDIA	36	217	19	8	1	1
C_C_Amer	19	80	13	35	11	5
S_o_Amer	39	232	32	14	9	21
E_Asia	4	15	18	4	6	11
Mala_Indo	1	40	14	9	1	2
R_SE_Asia	4	80	34	5	2	9
R_S_Asia	32	135	22	13	4	24
Russia	56	41	14	20	23	7
Oth_CEE_CIS	77	66	21	20	8	6
Oth_Europe	6	4	1	2	0	1
MEAS_NAfr	20	57	21	7	3	3
S_S_AFR	55	493	46	4	4	45
Oceania	27	109	7	11	8	24
Total	667	2593	854	321	187	382

Note: The reported emissions from processing sectors represent only additional to primary sectors emissions and do not include emissions from livestock farming and all other emissions already counted in the emissions from primary livestock sectors.

Table 2 – Direct and indirect emissions from cropping sectors ($MtCO_2eq$)

`	Paddy Rice	Wheat	Coarse Grains	Oilseeds	Sugar Crop	OthAgri
USA	11.37	21.16	88.32	36.23	3.20	115.86
EU27	2.60	20.09	28.08	16.17	9.75	145.74
BRAZIL	13.85	2.30	11.83	48.58	10.65	39.71
CAN	-0.01	8.69	5.20	8.30	0.22	16.23
JAPAN	12.18	0.70	0.08	0.05	0.29	19.33
CHIHKG	277.88	51.19	33.61	24.82	4.70	411.11
INDIA	114.70	75.58	15.10	39.60	8.43	100.54
C_C_Amer	2.95	0.36	5.36	1.58	1.87	21.95
S_o_Amer	17.95	9.22	15.40	32.92	2.61	50.64
E_Asia	15.71	0.95	1.23	0.47	0.39	21.27
Mala_Indo	58.16	0.07	1.14	2.05	0.47	9.87
R_SE_Asia	154.48	0.08	0.72	0.40	1.25	12.33
R_S_Asia	72.23	12.20	4.25	3.13	3.66	39.49
Russia	2.01	5.02	9.14	1.66	0.71	29.91
Oth_CEE_CIS	2.46	13.44	13.70	3.68	3.75	74.24
Oth_Europe	0.01	0.42	0.85	0.21	0.18	3.29
MEAS_NAfr	10.18	10.37	11.38	2.03	1.16	31.71
S_S_AFR	49.78	2.25	21.36	1.55	8.77	53.38
Oceania	0.88	2.80	1.14	0.50	0.94	16.20
Total	819.36	237	268	224	63	1213

Table 3 – Emissions leakage under 27$/$tCO_2eq$ emissions tax on all sectors and sequestration subsidy, without and with BTAs (%)

Policy Scenario	Only farm livestock	All livestock	Cropping	All non-livestock	All sectors
Annex1 noBTA	47	45	16	9	11
Annex1 BTA	-14	-13	5	3	2
EU noBTA	54	52	16	15	19
EU BTA	-53	-49	-15	0.1	-4

Note: Only farm livestock includes only unprocessed livestock sectors (dairy, ruminant and non-ruminant). All livestock includes both processed and unprocessed livestock sectors.

Table 4 – Changes in output, emissions, and emission intensities under 27$/t$CO_2$eq emission tax on all sectors and sequestration subsidy in Annex 1, without and with BTAs (%)

		Annex1 noBTA			Annex1 BTA		
Output (%)							
		Global	Annex 1	non-Annex 1	Global	Annex 1	non-Annex 1
	Only farm livestock	-0.81	-2.85	1.29	-1.01	-1.59	-0.42
	All livestock	-0.88	-1.87	1.31	-0.88	-1.12	-0.47
	EII	-0.28	-1.11	1.37	-0.23	-0.88	1.05
	All sectors	-0.32	-0.51	0.28	-0.32	-0.48	0.18
Emissions (%)							
		Global	Annex 1	non-Annex 1	Global	Annex 1	non-Annex 1
	Only farm livestock	-2.33	-17.43	2.72	-4.47	-15.65	-0.73
	All livestock	-2.44	-17.27	2.71	-4.54	-15.55	-0.72
	EII	-12.27	-31.70	2.38	-12.61	-31.39	1.53
	All sectors	-6.93	-17.38	1.62	-7.50	-16.95	0.22
Emissions Intensity (%)							
		Global	Annex 1	non-Annex 1	Global	Annex 1	non-Annex 1
	Only farm livestock	-1.51	-14.58	1.43	-3.45	-14.06	-0.31
	All livestock	-1.56	-15.40	1.41	-3.66	-14.43	-0.25
	EII	-11.99	-30.59	1.00	-12.38	-30.51	0.48
	All sectors	-6.61	-16.87	1.34	-7.18	-16.47	0.04

Table 5 – Changes in output, emissions, and emission intensities under 27$/t$CO_2$eq emissions tax on all sectors and sequestration subsidy in EU27, without and with BTAs, (%)

		EU27 noBTA			EU27 BTA		
Output (%)		Global	EU27	non-EU27	Global	EU27	non-EU27
	Only farm livestock	-0.18	-2.71	0.57	-0.21	-0.39	-0.16
	All livestock	-0.28	-1.98	0.48	-0.21	-0.53	-0.06
	EII	-0.14	-0.88	0.17	-0.10	-0.31	0.00
	All sectors	-0.10	-0.40	0.04	-0.10	-0.38	0.02
Emissions (%)		Global	EU27	non-EU27	Global	EU27	non-EU27
	Only farm livestock	-0.82	-18.03	1.08	-2.18	-14.32	-0.84
	All livestock	-0.89	-18.05	1.07	-2.22	-14.48	-0.82
	EII	-5.29	-38.20	0.45	-5.60	-37.86	0.02
	All sectors	-1.76	-16.96	0.48	-2.17	-16.21	-0.10
Emissions Intensity (%)		Global	EU27	non-EU27	Global	EU27	non-EU27
	Only farm livestock	-0.64	-15.32	0.51	-1.96	-13.93	-0.67
	All livestock	-0.61	-16.07	0.59	-2.01	-13.95	-0.76
	EII	-5.14	-37.32	0.28	-5.51	-37.55	0.02
	All sectors	-1.67	-16.56	0.44	-2.07	-15.84	-0.12

Table 6 – Comparison of this study with Burniaux et al. (2010)

	Policy Scenario	Emissions tax (USD/tCO2-eq)	leakage rate (%)	EV (%) World	EV (%) acting	EV (%) non acting	EII output (%) World	EII output (%) acting	EII output (%) non acting	World GHG emissions
This Study										
	Annex1 noBTA	27	11	-0.2	-0.2	-0.16	-0.29	-1.1	1.37	-11.9
	Annex1 BTA	27	2	-0.2	-0.1	-0.7	-0.24	-0.9	1.1	-12.5
	EU noBTA	27	19	-0.1	-0.2	0.01	-0.1	-0.9	0.2	-1.9
	EU BTA	27	-4	-0.1	-0.2	-0.1	-0.1	-0.3	-0.004	-2.4
Burniaux et al. (2010)										
	Annex1 noBTA	43.3	4.4	-0.6	-0.8	-0.3	-0.4	-1.5	0.9	-8.6
	Annex1 BTA	43.4	1.1	-0.6	-0.6	-0.6	-0.5	-1.5	0.6	-8.9
	EU noBTA	20.9	3.8	-0.1	-0.3	0.0	0.0	-0.4	0.1	-1.2
	EU BTA	22.2	-4	-0.1	-0.2	-0.1	-0.1	-0.4	0.0	-1.3

Note: Mapping between Burniaux et al. and our GTAP-AEZ-GHG aggregation is not perfect, though. In Burniaux's et al. study, the energy intensive industries (EIIs) are chemicals, metallurgic, other metal, iron and steel industry, paper and mining products. In GTAP-AEZ-GHG aggregation, chemicals, metallurgic, other metal, iron and steel industry are clustered within En_Int_Ind. However, paper products sector is included in Oth_Ind_Se aggregate, and represents only small part of the aggregate. Mining is within OthPrimSect. However, fisheries which is not energy intensive industry, is also within OthPrimSect. Therefore, only En_Int_Ind is considered as EII in the following table.

Table 7 – Decomposition of carbon leakage rates under 27$/$tCO_2$eq emissions tax on all sectors and sequestration subsidy for different policy scenarios (%)

	Only farm livestock			All livestock			Cropping			All sectors		
Policy Scenario	Int. Trade	Fossil Fuel Price	Total	Int. Trade	Fossil Fuel Price	Total	Int. Trade	Fossil Fuel Price	Total	Int. Trade	Fossil Fuel Price	Total
Annex1 noBTA	47	0	47	45	0	45	14	2	16	7	5	11
Annex1 BTA	-12	-2	-14	-12	-2	-13	2	3	5	-3	5	2
EU noBTA	55	-1	54	52	-1	52	15	1	16	14	5	19
EU BTA	-53	0	-53	-49	0	-49	-19	4	-15	-13	9	-4

Table 8 – Sensitivity analysis results

#	Policy Scenario		Only farm livestock	All livestock	Cropping	All sectors
1	Annex1 noBTA	original AE	47	45	16	11
	Annex1 BTA		-14	-13	5	2
	EU noBTA		54	52	16	19
	EU BTA		-53	-49	-15	-4
2	Annex1 noBTA	80% higher AE for all trade goods in all regions	75	72	23	17
	Annex1 BTA		-6	-5	8	3
	EU noBTA		88	84	25	29
	EU BTA		-54.76	-50.75	-15.04	-4.17
3	Annex1 noBTA	70% lower AE for all trade goods in all regions	12	12	5	7
	Annex1 BTA		-23.6	-22.7	-4.5	0.8
	EU noBTA		13.8	13.4	2.9	10.7
	EU BTA		-45.4	-43.3	-21.6	0.2
4	Annex1 noBTA	80% higher AE for manufacturing goods in all regions	46	45	16	14
	Annex1 BTA		-14	-13	3	3
	EU noBTA		53	51	16	23
	EU BTA		-52	-48	-17	-3
5	Annex1 noBTA	80% lower AE for manufacturing goods in all regions	47	46	16	8
	Annex1 BTA		-14	-13	6	0.2
	EU noBTA		55	54	15	14
	EU BTA		-55	-52	-14	-5

Note: Only Livestock includes only unprocessed livestock sectors (dairy, ruminant and non-ruminant). All livestock includes both processed and unprocessed livestock sectors

Appendix

Table A1 – Aggregation of GTAP regions

Code	Region in the model	GTAP regions	Group
USA	United States	United States	Annex I
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
BRAZIL	Brazil	Brazil	Non-Annex I
CAN	Canada	Canada	Annex I
JAPAN	Japan	Japan	Annex I
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
MEAS_NAfr	Middle East and North Africa	Rest of Middle East, Morocco, Tunisia, Rest of North Africa	Non-Annex I
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

Table A2 – Aggregation of GTAP sectors

Code	Sector in the model	GTAP commodities
Paddy_Rice	Paddy Rice	pdr
Wheat	Wheat	wht
CrGrains	Coarse grains	gro
Oilseeds	Oil seeds	osd
Sugar_Crop	Sugar cane, sugar beet	c_b
OthAgri	Other agriculture goods	v_f, pfb, ocr
Forestry	Forestry	frs
Dairy	Raw milk	rmk
Ruminant meat	Cattel, sheep, goat, horses	ctl, wol
Non Ruminant meat	Non-ruminant livestock	oap
Proc_Dairy	Processed dairy products	mil
Proc_Rum	Processed ruminant meat products	cmt
Proc_NonRum	Processed non-ruminant meat products	omt
vol	Vegetable oils and fats	vol
Bev_Sug	Beverages, tobaco, sugar	sgr, b_t
Proc_Rice	Processed Rice	pcr
Ofd	Food products n.e.c.	ofd
OthPrimSect	OtherPrimary: Fishery & Mining	fsh, omn
Coal	Coal	coa
Oil	Crude Oil	oil
Gas	Natural gas	gas, gdt
Oil_Pcts	Petroleum	p_c
Electricity	Electricity	ely
En_Int_Ind	Energy intensive Industries	i_s, nfm, fmp, crp
Other_transp	Other transport	otp
Water_transp	Water transport	wtp
Air_transp	Air transport	atp
Oth_Ind_Se	Other industries and services	tex, wap, lea, lum, ppp, nmm, mvh, otn, ele, ome, omf, cns, trd, cmn, ofi, isr, obs, ros
NTrdServices	Other services (Governmnet), dwellings, water	osg, dwe, wtr

Table A3 – Summary of scenarios

#	Policy Scenario	Abating Region	BTA	Emissions Tax	Sequestration Subsidy
1	*Annex1 noBTA*	Annex I	N/A	$27 /TCO2eq in all sectors	$27 /TCO2eq
2	*Annex1 BTA*	Annex I	$27 /TCO2eq on all imports from non-Annex I	$27 /TCO2eq in all sectors	$27 /TCO2eq
3	*EU noBTA*	EU27	N/A	$27 /TCO2eq in all sectors	$27 /TCO2eq
4	*EU BTA*	EU27	$27 /TCO2eq on all imports from non-EU27	$27 /TCO2eq in all sectors	$27 /TCO2eq

Table A4 – Total emissions from processed non-ruminant sector by region, $MtCO_2$-eq

	Simultaneously	Region by Region
USA	89.6	93.6
EU27	124.9	143.2
BRAZIL	50.7	47.8
CAN	6.4	4.6
JAPAN	2.6	6.1
CHIHKG	93.4	89.2
INDIA	1.1	0.0
C_C_Amer	5.9	5.0
S_o_Amer	31.5	26.6
E_Asia	16.3	18.0
Mala_Indo	2.9	2.0
R_SE_Asia	23.1	22.6
R_S_Asia	33.4	52.4
Russia	7.0	4.2
Oth_CEE_CIS	8.2	5.8
Oth_Europe	1.0	1.3
MEAS_NAfr	10.3	8.8
S_S_AFR	59.5	44.0
Oceania	24.5	17.0
Total	592.3	592.1