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Article

Why a Global Carbon Policy Could Have a Dramatic Impact on the Pattern of the Worldwide Livestock Production

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Abstract *The taxation of Greenhouse Gases (GHG) represents an efficient means of achieving climate change mitigation, and this is often the starting point in any discussion of long run global GHG reduction. However, the direct effects of such a tax, or equivalently, an emissions trading scheme, will vary across countries and sectors according to the emissions intensity of the sector. We report, for the first time, estimates of such livestock emissions intensities for all regions of the world and decompose the intensities to understand the sources of regional variation. Our findings indicate that most of the variation is due to differences in the value of output per animal in different regions, which in turn is due to regional differences in output per animal (yield) and dollar per unit output (price). Animals with relatively low annual output values tend to be characterized by higher economic emissions intensities. We find this to be the case in many developing countries. Livestock activity in these high emissions intensity regions are hit especially hard by an emissions tax, resulting in disproportionate reductions in output and consumption in many regions already suffering from malnutrition.*

Key words: Emissions intensity, CGE model, GHG taxation livestock emissions.

JEL Codes: F18, Q56, Q58.

Introduction

Developing and transitional economies generate a substantial share of global greenhouse gas emissions and have recently overtaken developed countries as the producers of the majority of anthropogenic emissions (Boden et al. 2011). Unlike developed countries, a disproportionate share of developing countries' emissions comes from agriculture and forestry activities. Similarly, a significant amount of low cost greenhouse gas abatement potential is estimated to be available in these sectors of developing countries (Golub et al. 2009). These considerations have clearly affected domestic and international climate change mitigation policy proposals. For instance, recent U.S. greenhouse cap-and-trade proposals permit the use of large quantities of international abatement (so-called "offsets") intended to limit the cost of achieving domestic abatement objectives. International discussions are seeking developing and transitional country abatement participation to achieve more aggressive climate objectives and to manage overall costs.

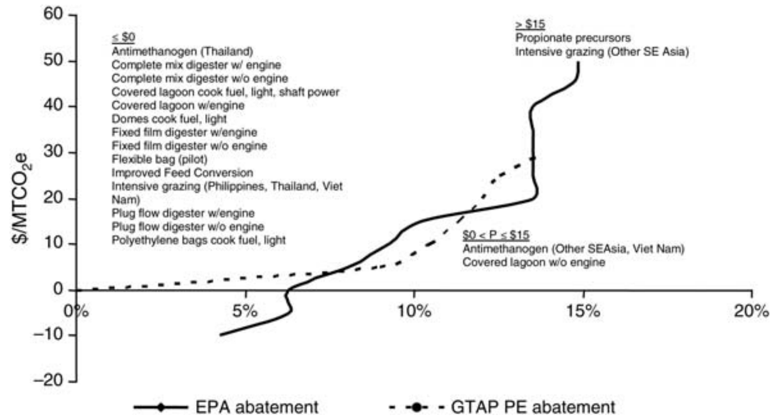
Developing countries understandably see opportunities for potential new revenue as suppliers of low-cost abatement. Livestock is one sector that could potentially contribute such abatement, with livestock sectors being responsible for a large share of direct, global, non-carbon dioxide greenhouse gas (non-CO_2 GHG) emissions, as well as having a significant role in emissions associated with land use change. Further, as a key food-producing and land-using sector, livestock GHG abatement is likely to have global economic impacts on agricultural production, consumption and trade. The size and distribution of these impacts are of interest to farmers, development planners, the private sector, multinationals, and non-governmental organizations. To date, there is a dearth of analysis of the impacts of climate policy on the global livestock industry. While livestock-specific emissions and mitigation cost and supply estimates have become available recently (for example, USEPA, 2006a, 2006b; IPCC, 2007; Golub et al., 2009), there is little analysis on the potential structural economic implications of a global livestock GHG abatement strategy.

Accordingly, this paper utilizes a global trade and environmental framework to analyze how the global distribution of livestock production, consumption and trade might be affected by a climate policy incentive for reducing GHG emissions associated with livestock production. This analysis focuses on short-term policy implications, with our results being estimates of annual average effects for a 20-year time horizon. The next section discusses regional differences in livestock emissions, and outlines why a GHG abatement policy might have differential regional impacts. We then embed these emission profiles within a global economic modeling framework to analyze the potential structural implications of GHG abatement policies on the global livestock industry.

Mitigation options

Livestock is directly responsible for approximately one-third of global non-CO_2 GHG emissions (Rose and Lee, 2009), and it is also the world's largest source category of methane emissions, most of which is derived from enteric digestion and manure from ruminant animals (Rose and Lee, 2009; Smith et al. 2008; US-EPA, 2006a). Animal manure is also a significant source of nitrous oxide emissions. The mitigation responses of the model used in this study are calibrated to marginal cost curves for abating livestock non-CO_2 emissions that were developed for our model aggregation

Figure 1 Marginal abatement cost schedule for dairy farms in Rest of South East Asia region



(Rose, 2011).[1] Figure 1 illustrates our calibration for the dairy sector of Southeast Asia, and lists some of the mitigation technologies for abating enteric and manure emissions that are adopted at different greenhouse gas price levels. Enteric emissions mitigation options include feed management to improve feed conversion efficiency, and dietary additives such as antimethanogens and propionate precursors. The improvement of productivity through intensive grazing also helps to reduce emissions per unit of output. Several types of anaerobic digesters, which capture methane emissions from manure storage facilities, also play an important role.

Some of the mitigation options listed in figure 1 suggest that they provide a small net benefit upon implementation (so-called "no-regrets" options). As noted by US-EPA (2006), these options should not be characterized as free or profitable, but instead as missing costs or having barriers to adoption. We therefore assume that these options attract a small cost by calibrating the model to include non-negative abatement costs. As shown in figure 1, emission reductions between 0-10% can be achieved at below \$10/($MTCO_2e$ = Metric tons of carbon dioxide equivalent) for the dairy sector in Southeast Asia, after which the costs steadily rise. Note that mitigation beyond 15% in this sector/region will be hard to achieve without reducing animal numbers.

Mitigation policies

A wide range of policy measures are suitable for encouraging GHG mitigation in livestock sectors. A comprehensive list of these measures is provided by Gerber et al. (2010). Of these, market-based instruments such as abatement subsidies, emission taxes and emission trading schemes, which establish a price for carbon, are known to be more cost efficient than

[1] *We developed custom agricultural mitigation supply curves for our 19 global regions based on the technologies and costs estimated by US-EPA (2006). The customized mitigation supplies take into account the specifics of our regional and sectoral aggregation, as well as the regional and sectoral GHG emissions not affected by the mitigation technologies (for example, biomass burning, fuel combustion, pasture/range/paddock). See Rose (2011) for details and the resulting mitigation supply curves. See Golub et al. (2009) for a description of the approach used for adjusting and calibrating our CGE production structure.*

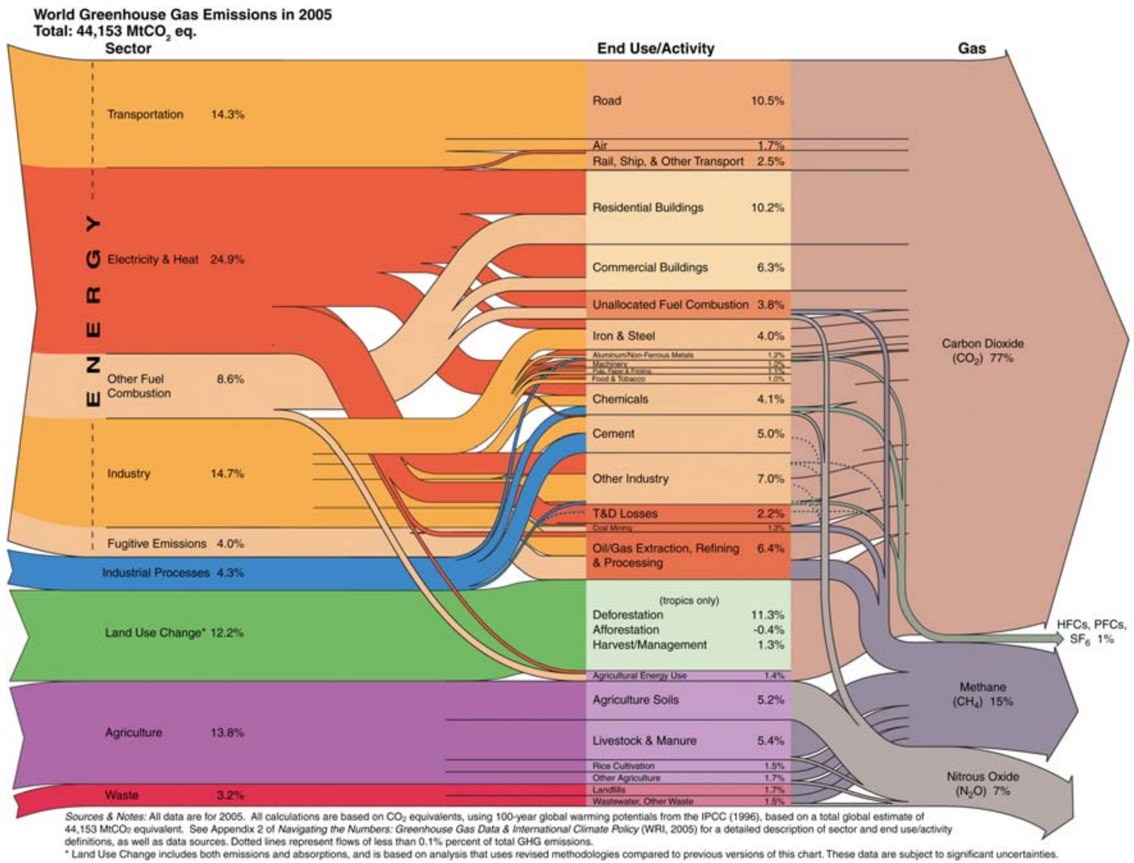
prescriptive regulations that mandate emission limits and/or specific technologies and practices, because they allow agents to mitigate in ways that are compatible with their individual business structures (Baumol and Oates, 1990). While the mitigation incentives of these market-based instruments are identical, an emissions subsidy can improve industry profitability relative to emission taxes and tradable permit schemes. In fact, in some cases it is possible for an abatement subsidy to cause expansion in production of the target industry and increase its emissions beyond what they would have been without the intervention (Baumol and Oates, 1990). Besides the effect of market-based instruments, climate change itself can also play a significant role in livestock abatement. As suggested by Seo (2010a), under hot and dry climatic conditions, crop-only systems decrease in Africa by 4.1%, and farmers switch to mixed systems, thereby increasing the share of livestock in overall output. However, in the mild and wet climate, farmers switch from livestock-only systems to crop-only or mixed systems. Moreover, as mentioned by Seo (2010b), if global temperatures do not change quickly, the mixed farm systems are more likely to weather the changes.

In this study we opt for the more environmentally effective option of an emissions tax, while recognizing this may not be the most equitable policy when applied uniformly across all regions, given the greater food security role that agricultural industries play in developing countries. There are also several implementation challenges for mitigation policies unique to agriculture. Unlike industrial point sources, most agricultural emission sources are quite diffuse, creating enormous challenges for emissions measurement and the verification of emission reductions. For the livestock sector, these challenges vary considerably between emission sources. Least problematic is the measurement of manure CH_4 emissions from large scale, intensive dairy, pig and feedlot enterprises, which are essentially point emission sources. These enterprises contrast sharply with small-scale livestock production – much of which is produced for home consumption – which dominates many of the world's poorest economies. Measuring enteric emissions mitigation also poses a considerable challenge to those seeking to regulate GHG emissions from livestock, owing to the complex biological processes that govern emissions. To date, these challenges have limited the application of market-based mitigation solutions to livestock. For example, the only activities that can currently supply offsets under the framework of the Kyoto Protocol relate to animal waste management (FAO, 2009). In addition to these practical implementation challenges, considerable political commitment is also needed to incorporate agricultural mitigation into international and national mitigation policies. While several developed countries have obligations to record and report agricultural emissions in UNFCCC national GHG inventories, few have so far incorporated agriculture into national mitigation policies and programs (Gerber et al., 2010).

Economic assessment of global livestock emissions

With the enforcement of new environmental regulations, governments, civil society and the private sector have become concerned about the impact of these policies on the relationship between economic production and climate change. Figure 2, created by the World Resources

Figure 2 World greenhouse gas emissions in 2005



Institute[2], provides a visual summary of global GHG emissions. From this, it can be seen that emissions associated with transportation accounts for approximately 14% of global emissions – nearly the same figure that applies to the agricultural sector – when land use change, which accounts for approximately 12% of global emissions, is omitted. Industry accounts for approximately 15% of emissions, and electricity generation tops the list of emissions sources, contributing nearly one-quarter of global GHG emissions.

Although it is commonsensical to expect that GHG taxation or emissions trading can help achieve the desired level of emissions, the effect of a tax or payment will vary across countries and sectors, and it may have unintended consequences for producers and consumers of the good in question. To further investigate this issue, we concentrate on the impact of GHG taxation in the most greenhouse gas intensive food production systems – namely livestock commodities (according to Rose and Lee (2009), one-quarter of global agriculture-related non-CO_2 emissions are generated by the ruminant meat sector).

The assessment of non-CO_2 GHG abatement technologies has been ongoing for some time (see, for instance, van Ham et al., 1994 and 2000, and more recently USEPA, 2006b). However, the economic evaluation of potential global scale penetration of these technologies is still relatively new (for example, Weyant et al., 2006), with only limited explicit assessment of agriculture's potential global role (Rose et al., in press; Golub et al., 2009; Smith et al., 2008). Still, these analyses are designed to inform high-level policy design questions regarding the feasibility and cost of climate change management objectives, and as a result they are fairly aggregated and lack economic detail. Indeed, they have not focused on the potential market and distributional implications for agricultural production, consumption, and trade, which are important policy implementation issues. This paper represents an initial exploration of these issues by looking more closely at the economics of abatement in the livestock sector, which is an important and growing consumption sector offering significant near-term abatement potential from known technologies. Livestock emissions abatement has also been shown to cost-effectively contribute to long-run abatement portfolios, and is tied to significant land-use change emissions (Smith, 2008).

In this analysis, we use the GTAP version 6 CO_2 and non-CO_2 greenhouse gas emissions databases. The latter was developed by USEPA and Purdue University's Global Trade Analysis Project (GTAP)[3]. Both databases have been designed for use in global economic models such as the GTAP model of global trade. This highly disaggregated information about emissions allows for considerable improvement of the modeling of emitting activities and emissions abatement strategies relative to earlier studies of this issue, which often treated agricultural abatement as a single aggregate[4]. For purposes of the current study, we will aggregate the most detailed greenhouse gas emissions data set to 19 regions and 29 sectors, wherein 15 sectors pertain to food production.

[2] *http://www.wri.org/chart/world-greenhouse-gas-emissions-2005.*
[3] *See Rose and Lee (2009).*
[4] *See Otto and Reilly (2008).*

Hertel et al. (2009) explain how the economic consequences of a carbon tax will be felt at the level of individual sectors. Considering a tax associated with GHG emissions stemming from the use of inputs, the change in the *ad valorem* equivalent tax rate on input i employed in production of commodity j in region r depends on the change in the specific tax, $\Delta\ \tau_{ijr}$, and the change in the price of the input in question: ΔP_{ir}:

$$\Delta t_{ijr} = [\varphi_{ijr}/P_{ir}] \cdot [\Delta\tau_{ijr} - (\tau_{ijr}/P_{ir}) \cdot \Delta P_{ir}]. \tag{1}$$

To understand this expression, first assume that the input is in perfectly elastic supply, so the price does not change. Then the change in the *ad valorem* power of the tax depends on the change in the specific emissions tax $\Delta\ \tau_{ijr}$, adjusted for the emissions intensity of the input, φ_{ijr}. The latter is equal to total emissions from use of the input in production, divided by the amount of input used. Dividing by the price of the input, P_{ir}, we obtain the emissions intensity in *tons of emissions per dollar of input purchased*. Thus, the economic impact of an emissions tax will depend not only on the size of the tax, but also on the economic emissions intensity. The larger the intensity (tons/\$), the greater the impact of a given \$/ton tax. Note that a change in the price of the emitting input also has an impact on the *ad valorem* power of the tax. However, in order to predict how market prices will change, we first need an economic model, which we present below.

Cross sectoral comparison

Let us assume that market prices don't change, so the first-order effect of a uniform carbon tax depends on the sector's GHG emissions intensity, measured as metric kilograms of carbon dioxide equivalent of output ($MkgCO_2e$). In order to compute a single emissions intensity factor for each sector, we multiply emission intensity φ_{ijr} by quantity of input i, sum over all inputs and divide by total costs of sector j in region r to obtain the following:

$$\sum_i \varphi_{ijr} Q_{ijr} / \sum_i P_{ir} Q_{ijr}. \tag{2}$$

Of the three livestock sectors, ruminant meat production has the highest intensity (14.3 $MkgCO_2e$/\$), followed by dairy farms (3.2 $MkgCO_2e$/\$) and non-ruminant meat production (3.03 $MkgCO_2e$/\$). Accordingly, we will focus here on ruminant meat production, with some discussion also of dairy and other meat production for the sake of contrast.

Emissions per dollar of livestock output can vary greatly across countries. Therefore, it is useful to decompose emissions intensity to understand the source of such differences. These variations can be explained by differences in emissions per animal (or animal emission intensities) and value of output per animal (or economic animal productivity).

Animal emission intensities

Estimates of GHG emissions per animal (measured in $MTCO_2e$), based on FAO livestock numbers for 2001, EPA estimates for non-CO_2 emissions, and GTAP CO_2 emissions, are reported in the first three columns of table 1. Animal numbers are standardized across regions and sectors

Table 1 Disaggregation of economic emissions intensities in livestock sectors

	Emissions intensity ($MTCO_2e$/animal)			Economic animal productivity ($/animal)			Economic emissions intensity ($MTCO_2e$/$)		
Regions	**Dairy farms**	**Ruminant**	**Non-ruminant**	**Dairy farms**	**Ruminant**	**Non-ruminant**	**Dairy farms**	**Ruminant**	**Non-ruminant**
United States	2.1	2.0	1.7	920	457	1,062	0.0023	0.0044	0.0016
European Union	3.6	3.2	1.4	1,430	558	1,146	0.0025	0.0058	0.0012
Brazil	2.9	3.1	2.2	226	56	460	0.0127	0.0547	0.0048
Canada	2.5	2.3	0.9	1,433	377	982	0.0018	0.0061	0.0010
Japan	2.1	2.1	2.0	2,061	1394	2,186	0.0010	0.0015	0.0009
China and Hong Kong	6.0	4.6	1.5	1,455	190	750	0.0041	0.0243	0.0019
India	2.7	2.2	4.0	1,605	70	3,758	0.0017	0.0309	0.0011
Central and Caribbean Americas	2.5	2.7	0.9	733	217	1,024	0.0034	0.0125	0.0008
South and Other Americas	3.3	2.7	2.1	768	158	847	0.0043	0.0174	0.0025
East Asia	4.1	3.2	3.5	2,362	622	3,225	0.0018	0.0051	0.0011
Malaysia and Indonesia	4.3	4.1	2.7	995	82	926	0.0043	0.0494	0.0029
Rest of South East Asia	3.2	3.7	2.0	316	53	856	0.0101	0.0688	0.0023
Rest of South Asia	2.6	2.8	8.2	559	93	2,052	0.0047	0.0301	0.0040
Russia	4.7	5.1	1.7	559	481	985	0.0085	0.0105	0.0017
Other East Europe	4.5	4.2	1.2	1,603	849	2,655	0.0028	0.0050	0.0004
Rest of European Countries	3.5	3.4	1.2	1,717	806	2,706	0.0020	0.0042	0.0005
Middle Eastern and North Africa	3.8	3.0	5.7	1,733	607	3,660	0.0022	0.0049	0.0016
Sub-Saharan Africa	3.1	4.5	5.0	66	108	733	0.0464	0.0413	0.0069
Oceania countries	3.7	3.7	2.4	669	324	1,140	0.0055	0.0114	0.0021
Coefficient of variation	0.29	0.27	0.72	0.58	0.90	0.65	1.58	0.98	0.79

Source: FAO and GTAP version 6 database.

based on U.S. cattle carcass weight equivalents (for example, based on carcass weights, one U.S. cow is equivalent to 10.7 U.S. sheep and 0.8 Japanese cows). Thus, emissions per animal unit crudely represent emissions per unit of standing biomass in each sector, and they vary between countries depending on production characteristics that include animal genetics, feed composition, feed volume and manure management practices. Within a region, emissions per animal unit are similar between dairy and ruminants in most regions, while they tend to be lower on average for non-ruminants.

For validation purposes, it is useful to compare the aggregate estimates in table 1 (based on national data) to other sources. For example, the U.S. Environmental Protection Agency estimates that an adult cow in the U.S. produces 80-110 Kg of methane per year[5], which is the main non-CO_2 emission from ruminant livestock. Compared to CO_2, methane has 21 times more power to warm the atmosphere[6] (global warming potential). Thus, when converted to CO_2 equivalent emissions, this yields 1.68-2.31 MTCO_2e/animal of methane emissions per year. As we can see from table 1, our GTAP-based estimates for animal emission intensities in the U.S. (2.1 MTCO_2e/animal) are comfortably within this range.

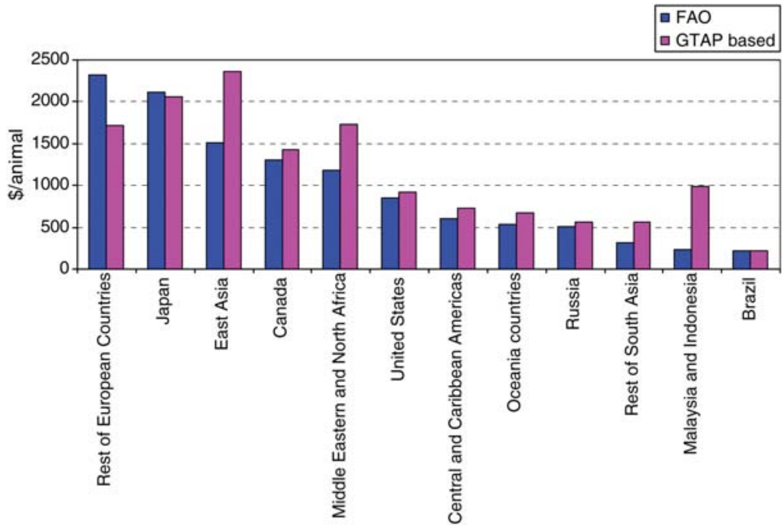
Economic animal productivity

Output value per animal unit, which is a measure of economic animal productivity, is calculated by dividing the value of annual output at market prices in the GTAP version 6 database by the FAO livestock numbers for 2001[7]. These values are presented in the second block of columns in table 1. Here, we see much greater variation across countries than for the emissions per animal unit in the dairy farm and ruminant sectors. For example, annual output flows for dairy farms range from \$66/animal in Sub-Saharan Africa to \$2,362/animal in East Asia, *a 36–fold difference.* This naturally raises the question of measurement error. To what extent is this due to inconsistencies between the GTAP database (the source of output values) and the FAO data base, which provides the estimates of animal numbers? To answer this, we turn to figure 3, which plots our GTAP-based estimates of output value against those calculated based on FAO data on value of output by livestock industry[8], where available. As can be seen from the figure, the two series show strong agreement. And where there are differences between the two, they do not seriously alter the overall ranking of intensities across regions.

More striking than the variability between regions within each sector is the dramatically higher value of output per dairy cattle and non-ruminant animal units compared to ruminant animal units. This can largely be explained by the inherently higher feed conversion efficiencies of dairy and non-ruminant sectors – which generate far more output from an equivalent unit of standing biomass (or animal overhead). Better-quality feed rations and the continuous production of milk leads to far more output per animal unit in the dairy sector compared with the ruminant sector, which relies solely on harvesting live biomass. On the contrary,

[5] *http://www.epa.gov/rlep/faq.html#1.*
[6] *http://www.epa.gov/methane/scientific.html.*
[7] *http://faostat.fao.org/site/573/default.aspx#ancor.*
[8] *http://faostat.fao.org/site/613/default.aspx#ancor.*

Figure 3 FAO- and GTAP-based dairy output values per animal, ($/animal)



much higher weight gain rates for non-ruminant animals, particularly poultry, result in significantly higher animal productivity compared with ruminant meat production (Wirsenius, 2003). Indeed, only 4% of feed energy is used to maintain the parental population in broiler production systems, compared to between 50-70% in ruminant meat production systems (Sinclair and Webb, 2005).

Decomposition of emissions intensity

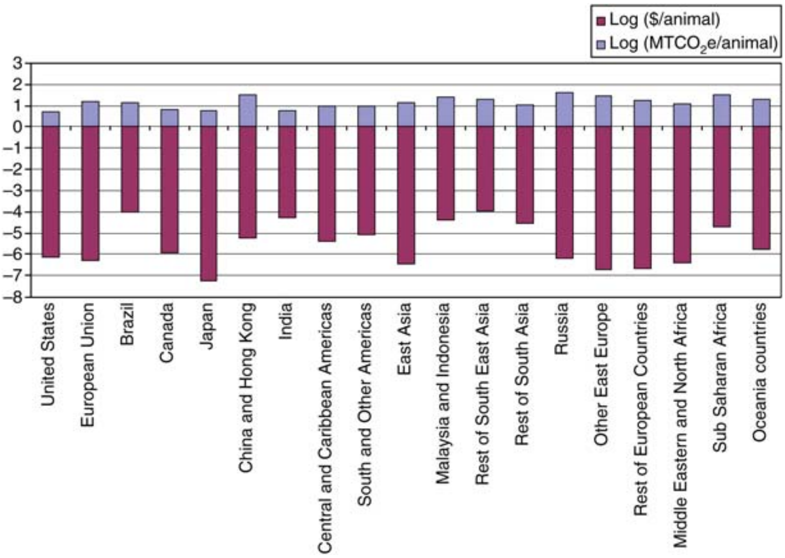
Having estimated the two components of the emissions per dollar of output, we are in a position to assess the relative contribution of each factor to overall variation in ruminant livestock emissions factors by region. The comparison of coefficients of variation in emissions per animal (0.27) and economic animal productivity (0.9) in the ruminant sector reported at the bottom of table 1 reveals that differences in economic animal productivity is a more important factor in the regional variation of ruminant livestock emissions intensities. Since the emissions intensity per dollar of output is simply the product of the two factors, it is useful to present these in log-linear form (appendix - table A.1) to demonstrate the effect of each factor on the total outcome[9]. This logarithmic decomposition is plotted in figure 4 and confirms that differences in *economic animal productivity* dominate regional variations in the overall levels of emissions per dollar of output for ruminants.

To better understand the variations in economic animal productivity, we can decompose it into differences in output prices and physical output per animal (or physical animal productivity)[10]. Output per animal is a widely recognized factor in GHG emissions inventory methods (IPCC, 2006), as

[9]*Emissions intensity (MTCO2e/animal)* $\times \frac{1}{\text{Economic animal productivity}(\$/\text{animal})}$ *=Economic emissions intensity (MTCO2e/$) So that:* Log *[Em. intens. (MTCO2e/animal)]*+Log *[Economic animal productivity ($/animal)]*$^{-1}$=Log *[Ec. em. intens. (MTCO2e/$)].*

[10]*Economic animal productivity ($/animal) = Output price ($/kg) x Physical animal productivity (kg/animal).*

Figure 4 Decomposition of emissions per dollar of ruminant output



well as the focus of some livestock GHG abatement technologies that seek to improve output per animal and thereby reduce emissions per unit output (for example, USEPA, 2006b). With the FAO price[11] and output per animal[12] data for 2001, we can determine the effect that each component has[13]. See appendix figures A.1a and A1.b for examples for cattle meat and cow milk. Overall, in developed economies such as the U.S. and European Union (EU) countries, yield per animal is much higher than in developing countries. Price is also higher. Since economic animal productivity is the product of these two, it is not surprising that it can be an order of magnitude larger in the rich countries. However, which factor dominates depends on the livestock commodity and country, although it is the yield differences which generally dominate. We also compute coefficients of variation to determine the contribution of each factor to the variation in value of output across regions. In the case of cow milk, the largest portion of the variation in the value of output per animal is due to variation in livestock yield per animal (coefficient of variation 0.74), as opposed to prices (coefficient of variation 0.62). In contrast, for beef, output prices contribute most to the variation, with a coefficient of variation of 0.84, versus 0.36 for yield per animal. If price reflects the quality of a product, then these findings reflect the fact that milk is a more homogenous product. Thus, prices do not vary much across countries. Meat, on the other hand, may have very different quality attributes reflected in its prices.

Implications for global GHG taxation of the livestock industries

In our analysis of the effects of GHG taxation on livestock sectors, we employ the computable general equilibrium model described in

[11] *http://faostat.fao.org/site/570/default.aspx#ancor.*
[12] *http://faostat.fao.org/site/569/default.aspx#ancor.*
[13] *For this purpose we use a log-linear form:* Log*[Econ. anim. productivity ($/animal)]* =Log *[Output price ($/kg)]*+Log *[Phys. anim. productivity (kg/animal)].*

Golub et al. (2009, 2010). This is a modified version of the GTAP model of global trade (Hertel, 1997), which incorporates land use by Agro-Ecological Zone, as well as GHG emissions. A description of the model is presented in the appendix. Abatement responses in the three considered livestock sectors are calibrated based on non-CO_2 GHG mitigation possibilities derived from detailed engineering and agronomic studies developed by the U.S. Environmental Protection Agency (USEPA, 2006; figure 1).

We develop four GHG taxation scenarios to analyze the impact of a global carbon policy on the pattern of production, consumption and trade in the worldwide livestock industry. As shown in table 2, in each scenario we impose a global GHG tax of \$27.3/MTCO$_2$e (equivalent to \$100/MTCe) on selected livestock sectors, *applied only to the portion of livestock not used for self-consumption*.[14] For the sake of simplicity, we focus exclusively on taxation of the livestock industries in this paper. This permits us to readily draw out the implications of the differences in livestock intensities across regions. However, in other simulations undertaken involving an economy-wide tax on carbon, we find that the ranking of output impacts across sectors and regions is little changed.

It is also reasonable to ask whether the carbon price chosen for this paper (\$27.3/MTCO$_2$e) is a reasonable value: we believe it is. The current futures price for carbon in the European Energy Exchange at the time of this drafting was roughly \$24US/MTCO$_2$e (EEA, 2011). A 2008 Review Commissioned by the Australian Government recommended implementation of an emission trading scheme in 2010 with a permit price equal to \$20AU/MTCO$_2$e (Garnaut, 2008); and Japan recently entertained a carbon tax of roughly \$20US/MTCO$_2$eq (Thomson-Reuters, 2009).

The highest emissions intensity is in the ruminant meat sector. Therefore, we choose ruminant meat for our main analysis. Emissions associated with enteric fermentation, and manure management in ruminants and non-ruminants are tied to livestock output to better facilitate calibration to EPA's abatement cost estimates (Golub et al. 2010). The emissions are treated as an input into the production process and can substitute with a composite consisting of all other production inputs. Thus, emission intensities in livestock sectors change under the imposition of carbon tax. Figure A.2 in the appendix shows initial and resulted (in each scenario) emissions intensities in three livestock sectors.

Table 2 Livestock taxation scenarios

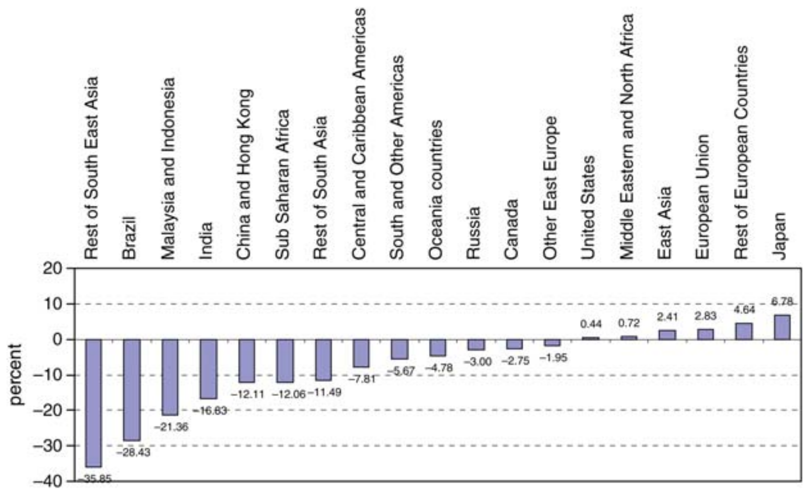
Sector Scenario	Ruminant meat	Non-ruminant meat	Dairy farms
RUMCO2TAX	√		
NRUMCO2TAX		√	
DAFCO2TAX			√
LIVCO2TAX	√	√	√

[14]*This is achieved by omitting the disposition of livestock output from the farm sector directly to home consumption, which is separately identified in the GTAP data base.*

Scenario RUMCO2TAX

Under the **RUMCO2TAX** scenario, the global GHG tax on ruminant meat reduces its output mainly in regions with higher emissions intensities (figure 5).[15] The largest decrease occurs in Rest of South East Asia region, which has the highest emissions intensity (69.75 MkgCO_2e/$) across all regions. There are significant ruminant meat output reductions also in Brazil and Malaysia-Indonesia, again, due to high emissions intensities (54.05 MkgCO_2e/$ and 49.7 MkgCO_2e/$, respectively).

Figure 5 Scenario RUMCO2TAX - change in ruminant meat output, percent change



More detailed changes in production and consumption, as well as exports and imports of ruminant meat are presented in table 3, which reports on the responses of regional producers and consumers to changes in relative input and output prices triggered by the climate policy. Global ruminant meat production and consumption fall by 4.9%, and we find that regions with higher emissions intensities reduce their exports of ruminant meat (and increase imports), while wealthier economies with lower emissions intensities such as the United States, EU countries and Japan, gain comparative advantage and increase production and net exports to regions with higher emissions rates. We can also see from table 3 that for these regions the trade balance (the change in exports less imports) for ruminant meat and ruminant products combined improves as a result of positive changes in production. In Canada, Eastern Europe and Oceania, net exports grow, but the ruminant meat output declines. In these regions the corresponding decrease in consumption is large enough to generate growth in the trade balance (table A.2a in the appendix reports changes in bilateral exports and imports of ruminant meat and changes in bilateral trade flows to all products combined are shown in table A.2b).

To further study the impacts of a global GHG tax on livestock, we concentrate on changes in emissions, reported in table 4. Under **RUMCO2TAX,** carbon dioxide, nitrous oxide and methane emissions

[15]*For the sake of comparison, we illustrate the differences in output changes when the GHG tax is imposed on the entire ruminant meat output and when it is applied only to the fraction of ruminant meat not used for self-consumption (appendix - figure A.3).*

Table 3 Scenario RUMCO2TAX - change in ruminant meat production, consumption, and trade balance

	Ruminant meat		Change in trade balance for ruminant meat and ruminant meat products combined, *$US million*
Regions	**Production,** *percent change*	**Consumption,** *percent change*	
United States	0.4	−5.6	1228
European Union	2.8	−4.4	1762
Brazil	−28.4	−21.5	−1368
Canada	−2.7	−4.3	111
Japan	6.8	−2.1	392
China and Hong Kong	−12.1	−12.5	−1486
India	−16.8	−7.8	−48
Central and Caribbean Americas	−7.8	−7.2	−331
South and Other Americas	−5.7	−8.6	−15
East Asia	2.4	−4.6	45
Malaysia and Indonesia	−21.4	−12.9	−207
Rest of South East Asia	−35.9	−17.6	−449
Rest of South Asia	−11.5	−7.3	−28
Russia	−3.0	−3.0	−36
Other East Europe	−2.0	−2.5	198
Rest of European Countries	4.6	−5.1	56
Middle Eastern and North Africa	0.7	−2.8	294
Sub-Saharan Africa	−12.1	−10.6	−567
Oceania countries	−4.8	−8.0	471
Total	−4.9	−4.9	22

**Note: the global net trade balance is non-zero due to the fact that these products also embody trade and transport services, which also change.*

decline globally, while F-gas emissions increase. The latter is due to a small increase in the output of electricity, energy-intensive industries, and other industry and services in the majority of regions as economic activity is shifted out of agriculture. This is a direct result of the fact that we are not taxing GHG emissions from these other sectors in this stylized scenario. Global emissions decrease by 451 million $MTCO_2e$, and GHG emissions decline in every region save Japan. The rise in emissions in that region can be explained by its very low ruminant emissions intensity, coupled with the rise in world prices for ruminant products. Indeed, Japan has the lowest emissions per dollar of output (1.47 $MkgCO_2e/\$$) in the ruminant meat sector across all regions.

With sharply different changes in regional production and consumption, we expect to see significant changes in trade patterns. This is indeed the case (appendix – table A.2a-b), and the resulting changes in bilateral trade affect the use of transport (domestic and international), and, therefore, transport emissions. However, our analysis reveals that the changes in global transport emissions (-0.3 million $MTCO_2e$) are relatively small

Table 4 Scenario RUMCO2TAX - change in emissions (10^3 $MTCO_2e$)

Regions	RUMCO2TAX				
	CO_2	N_2O	CH_4	FGAS	Total
United States	53	−5,887	−6,439	−22.3	−12,295
European Union	40	−2,658	−2,680	−33.5	−5,331
Brazil	−1,337	−32,661	−85,823	49.8	−119,771
Canada	−36	−511	−1,131	−4.3	−1,683
Japan	190	499	70	−8.1	751
China and Hong Kong	−1,648	−9,175	−32,791	109.7	−43,505
India	−572	−1,431	−34,037	5.3	−36,035
Central and Caribbean Americas	−190	−1,704	−7,875	0.9	−9,769
South and Other Americas	−19	−8,688	−17,112	2.6	−25,816
East Asia	−78	−159	−256	−2.5	−496
Malaysia and Indonesia	−77	−1,711	−6,659	−0.2	−8,448
Rest of South East Asia	−127	−6,406	−20,326	0.0	−26,858
Rest of South Asia	−68	−2,696	−9,276	0.2	−12,040
Russia	−1,186	−459	−1,532	−12.9	−3,190
Other East Europe	−2,009	−1,173	−3,024	−5.8	−6,211
Rest of European Countries	−4	−41	32	−3.4	−15
Middle Eastern and North Africa	−629	172	−118	−4.9	−579
Sub-Saharan Africa	971	−37,373	−90,804	42.8	−127,163
Oceania countries	−511	−2,083	−9,440	−2.9	−12,037
Total	−7,238	−114,143	−329,221	110.3	**−450,491**
Global transportation	−168	20	−142	0	**−291**
Global ruminant meat	−2,958	−107,910	−330,747	0	**−441,615**

(appendix – table A.4a) compared to those GHG emissions changes due to the relocation and reduction of ruminant meat production (-442 million $MTCO_2e$).[16] This relates to the recent "food miles debate", and is extensively analyzed in Avetisyan et al. (2010). Those authors use this same framework to evaluate the emissions-trade tradeoff, and test whether the substitution of domestic for imported ruminant products decreases consumption-related direct and indirect GHG emissions. Avetisyan et al. (2010) conclude that increased consumption of domestically-sourced ruminant products reduces global emissions, mainly due to increased production in regions with relatively lower emissions intensities in the ruminant products sector and not because of lower transport requirements.

Table 5 reports the ruminant meat emissions intensity by region alongside the percentage change in emissions. From this, we see that the largest percentage of reductions in emissions arise in those regions with the highest emissions intensities. Depending on the size of the overall economy, as well as the ruminant emissions intensity, we see varying absolute contributions to the global emissions reduction (third column of table 5). The largest contributions to GHG reductions are in Brazil and Sub-Saharan Africa.

[16] *Figure A.4. in the appendix reveals that the change in the share of domestic ground transport use (negative in most regions) is greater than that of international ground transport (positive in most regions). The other two transport modes show similar results.*

Table 5 Scenario RUMCO2TAX – ruminant meat emissions intensity and changes in global emissions

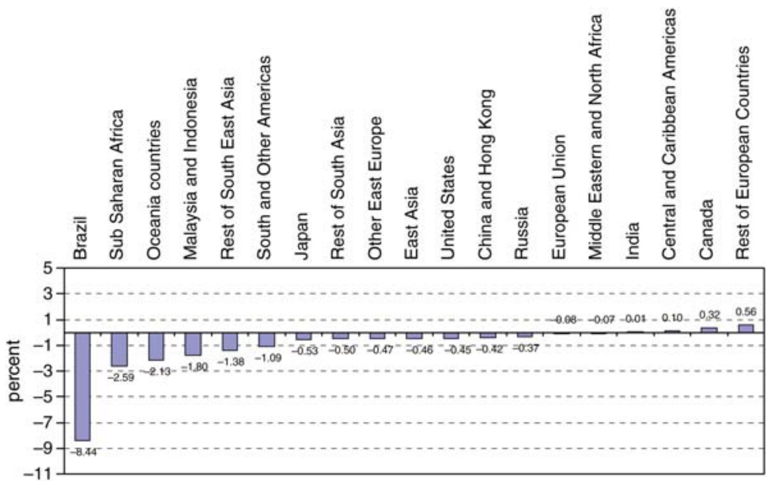
Regions	Ruminant meat emissions intensity, MkgCO2e/$	Change in emissions	
		Percent	10^3 MTCO2e
United States	4.45	−0.17	−12,295
European Union	5.74	−0.11	−5,331
Brazil	54.05	−14.92	−119,771
Canada	6.06	−0.24	−1,683
Japan	1.47	0.07	751
China and Hong Kong	24.63	−0.96	−43,505
India	31.04	−2.38	−36,035
Central and Caribbean Americas	12.75	−1.15	−9,769
South and Other Americas	17.91	−2.71	−25,816
East Asia	5.15	−0.06	−496
Malaysia and Indonesia	49.72	−1.28	−8,448
Rest of South East Asia	69.75	−3.78	−26,858
Rest of South Asia	30.32	−2.88	−12,040
Russia	10.44	−0.17	−3,190
Other East Europe	4.95	−0.40	−6,211
Rest of European Countries	3.91	−0.01	−15
Middle Eastern and North Africa	5.28	−0.03	−579
Sub-Saharan Africa	41.82	−9.01	−127,163
Oceania countries	11.42	−1.91	−12,037
Total		**−1.38**	**−450,491**

Scenario NRUMCO2TAX

The emissions intensities per dollar of non-ruminant meat output are lower compared to that of ruminant meat. Therefore, we anticipate a global GHG tax imposed on the portion of non-ruminant meat production that excludes self-consumption to generate a relatively modest reduction in output. As expected, the output of non-ruminant meat decreases in almost all regions under scenario **NRUMCO2TAX**. The largest output reduction happens in Brazil (-8.44% in figure 6), which has a relatively high emissions intensity of 8.14 MkgCO_2e/$ (table 1). More detailed changes in the production and consumption of non-ruminant meat are illustrated in table A.5 in the appendix.

Since non-ruminant meat is less emissions intensive, the same GHG tax on this sector (**NRUMCO2TAX)** yields less reduction in global emissions (-94 million MTCO_2e, table A.3a in the appendix) compared to that in scenario **RUMCO2TAX** (-451 million MTCO_2e). The highest reduction, which actually derives from nitrogen oxide emissions, i.e., fertilizer used to produce feedstuffs and enhance pasture productivity, takes place in the China and Hong Kong region (-17 million MTCO_2e), while the least GHG abatement occurs in the Rest of Europe region (-62,000 MTCO_2e). This follows almost the same pattern as the change in output, as expected (appendix – table A.3a). The United States and the EU have similar emissions intensities and comparable size of the non-ruminant meat sector, and, thus, experience similar reductions in emissions.

Figure 6 Scenario NRUMCO2TAX - change in non-ruminant meat output, percent change

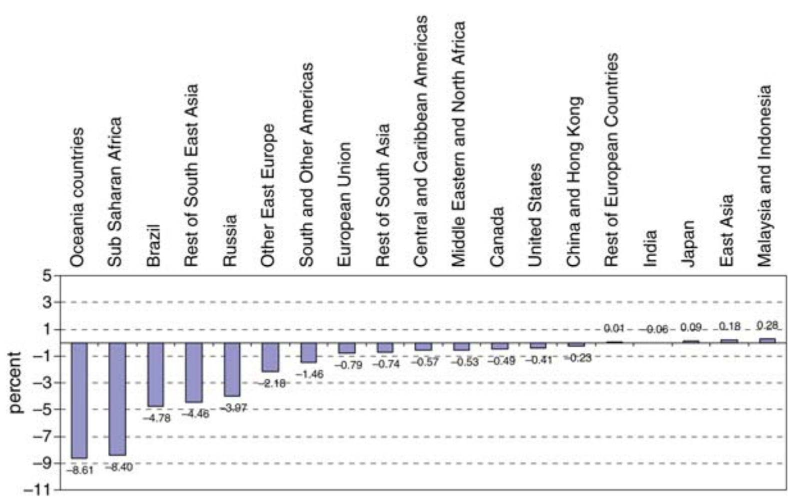


It is interesting that under **NRUMCO2TAX,** Brazil, Japan and Other Eastern European countries experience a similar reduction in transportation emissions (appendix – table A.4b), which comes mostly from ground transportation. South and Other Americas and Rest of South East Asia have comparable transportation emissions intensities, and thus experience similar changes in transportation emissions.

Scenario DAFCO2TAX

Similar to previous scenarios, a global GHG tax imposed on raw milk output (excluding home consumption) negatively affects production in the majority of regions. We can see that in figure 7, the output of dairy farms is reduced in almost all regions, and the largest reduction takes place in Oceania countries (-8.61%) and Sub-Saharan Africa (-8.4%). Again, the reason is the relatively higher emissions intensity in the dairy farms sector

Figure 7 Scenario DAFCO2TAX - change in dairy farms output, percent change



of these regions. Details on production and consumption changes of dairy farms are given in table A.6 in the appendix.

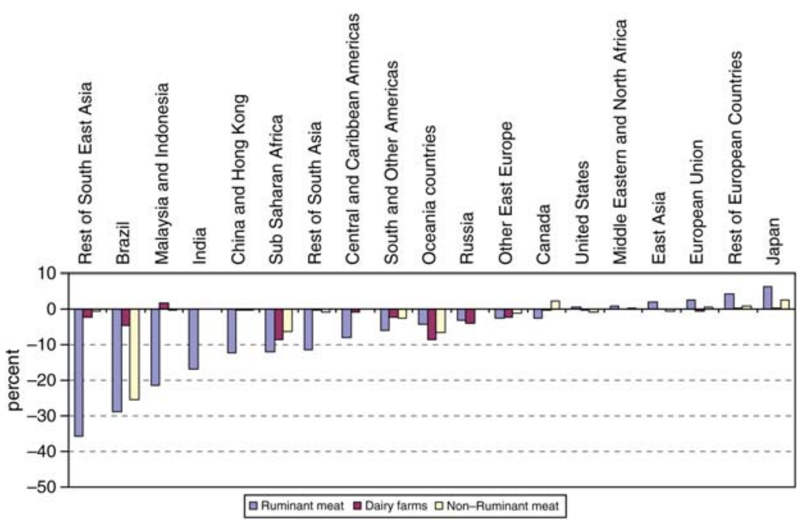
Scenario **DAFCO2TAX** generates a very small reduction in global emissions compared to the other two scenarios (-72 million $MTCO_2e$) (appendix – table A.4b). There are two main reasons for such an outcome. First, dairy cows are extremely productive (high value of output per animal) and therefore have lower economic emissions intensities. Second, the bilateral trade pattern of dairy products is very different. From table A.4b in the appendix, we see that the highest reduction in emissions occurs in the United States (-19.8 million $MTCO_2e$), which is mostly because of a decrease in its total exports by $260,000,000. The EU also experiences significant GHG reduction – amounting to 17.1 million $MTCO_2e$ – with the largest exports of dairy products across all regions ($21,190,000).

Similar to **RUMCO2TAX**, the domestic transportation component is the main factor affecting transportation emissions under scenario **DAFCO2TAX**. As already mentioned, the bilateral trade volumes of dairy products are lower than that of non-ruminant products, and mainly ground transport is affected. We can see from table A.5c in the appendix that the highest reduction in transportation emissions occurs in the Other Eastern Europe region (-254,871 $MTCO_2e$), which is represented by the Commonwealth of Independent States (CIS).

Scenario LIVCO2TAX

In this scenario we impose a global GHG tax simultaneously on all three livestock sectors' output, excluding home consumption. The changes in the ruminant meat sector under scenario **LIVCO2TAX** are similar to those in scenario **RUMCO2TAX** (figure 8). Again, the largest percentage ruminant meat output reduction (-35.8%) happens in the Rest of South East Asia region, which has the highest emissions rate for ruminant meat per dollar of output (69.8 $MkgCO_2e/\$$) across all regions. The highest reduction in the output of two other livestock sectors is -8.58% for dairy farms in Oceania countries and -25.5% for non-ruminant meat in Brazil.

Figure 8 Scenario LIVCO2TAX - change in livestock output, percent change



Due to higher emissions intensity in ruminant meat, the effect of the GHG tax is more significant in the ruminant meat sector. Changes in the production and consumption of three livestock sectors are presented in table A.6 in the appendix.

Similar to the previous two cases, all regions experience reductions in emissions. The smallest abatement arises in Japan, which is mainly due to lower emissions intensity in its ruminant meat sector, as noted previously (see also appendix – table A.4c).

A global GHG tax on all three livestock sectors (**LIVCO2TAX**) decreases emissions from transport activities, mostly in regions with relatively higher economic emissions rates (appendix – table A.5d). The largest increase is in the United States and the EU, which have lower emissions intensities and expand their livestock operations under the global tax to fill the gap in global production, and thus become net exporters. The largest reduction in transport-related emissions occurs in Sub-Saharan Africa, followed by Brazil. These reductions are due to their status as regions with high emissions intensities and which therefore show large reductions in output under the GHG tax. Indeed, these two regions are characterized by the highest emissions intensities in non-ruminant meat (Sub-Saharan Africa – 13.47 MkgCO_2e/$ and Brazil – 8.14 MkgCO_2e/$) and dairy farms (Sub-Saharan Africa – 46.5 MkgCO_2e/$, and Brazil – 12.56 Mkg$CO_2$e/$) sectors, and also show relatively high economic emissions rates for ruminant meat (Sub-Saharan Africa – 41.82 MkgCO_2e/$, and Brazil – 54.05 Mkg$CO_2$e/$).

Conclusions

In this paper we investigate the market implications of potential emissions reduction incentives facing the global livestock sector. Although the livestock sector is not going to be the world's principal abatement sector over the long-run, it nonetheless represents a growing source of emissions, has near-term abatement potential from known technologies, can cost-effectively contribute to long-run pollution abatement portfolios, and is tied to significant land-use change emissions. For all these reasons the livestock sector has important implications for policies aimed at reducing GHG emissions.

This paper presents, for the first time, estimates of the *economic* emissions intensity of livestock production around the world. We show that these emissions intensities vary tremendously by region, with the highest emissions intensities present in the poorest countries due to their relatively low value of output per animal. As a consequence, when a global emissions tax is imposed on one or more of the global livestock sectors, there is a sharp change in comparative advantage, with production shifting to richer countries. Therefore, increasing the value of output per animal or the yield per animal in developing countries will reduce the negative impact of a global carbon tax on the livestock output of such countries.

As expected, a global GHG tax generates larger emissions reductions in countries with higher emissions intensities, especially under the tax on ruminant meat production. Regions with relatively low emission intensities in livestock sectors exploit their comparative advantage. Thus, the country with the lowest emissions intensity per dollar of ruminant meat output – Japan – gains some advantage and tends to increase the output of ruminant meat and ruminant products under the global GHG tax. In the case of non-ruminant meats, the impact of a tax is much smaller, due to its lower emissions intensity per dollar of output, as well as the presence of more economical abatement options.

In our analysis we have considered a global GHG tax on the fraction of output of livestock sectors that excludes home consumption. However, it is more likely that we will see a combination of programs that tax activities in some sectors and regions and subsidize abatement in others. Future research should explore the impacts of more complex global abatement schemes for the livestock sector. It is clear that future climate mitigation strategies cannot ignore the livestock industry due to its large contribution to emissions. Furthermore, given the great variation in emissions intensities across regions, such global action is likely to have a strong impact on international patterns of production, consumption and trade.

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Supplementary Material

The appendicies are available as supplementary material at *Applied Economic Perspectives and Policy* online (http://aepp.oxfordjournals.org/).

References

Avetisyan, M., T. Hertel, and G. Sampson. 2010. Is Local Food More Environmentally Friendly? The GHG Emissions Impacts of Consuming Imported vs. Domestically Produced Food. Draft manuscript, *Center for Global Trade Analysis*. Purdue University, West Lafayette, IN.

Baumol, W. J., and W. E. Oates. The Theory of Environmental Policy, 2nd ed. Cambridge University Press, Cambridge; 1990.

Boden, T., G. Marland, and R. Andres. 2011. Global, Regional, and National Fossil-Fuel CO_2 Emissions. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A. doi: 10.3334/CDIAC/00001_V2011.

Burniaux, J., and T. Truong. 2002. "GTAP-E: An Energy-Environmental Version of the GTAP Model". GTAP Technical Paper No. 16, *Center for Global Trade Analysis*. Purdue University, West Lafayette, IN.

EEA (European Energy Exchange). 2011. European Carbon Futures. Accessed June 20, 2011. http://www.eex.com/en/Market%20Data/Trading%20Data/Emission%20Rights/European%20Carbon%20Futures%20|%20Derivatives.

Garnaut, R. (2008) The Garnaut Climate Change Review Final Report. Cambridge University Press, UK.

Gerber, P., N. Key, F. Portet, and H. Steinfeld. 2010. Policy options in addressing livestock's contribution to climate change. *Animal* 4(3): 393–406.

Golub, A., T. W. Hertel, H.-L. Lee, S. Rose, and B. Sohngen. 2009. The Opportunity Cost of Land Use and the Global Potential for Greenhouse Gas Mitigation in Agriculture and Forestry. *Resource and Energy Economics* 31(4): 299–319.

Golub, A., B. Henderson, T. Hertel, S. Rose, and M. Avetisyan. 2010. Effects of GHG Mitigation Policies on Livestock Sectors. Paper presented at the 13th Annual Conference on Global Economics Analysis, Penang, Malaysia, June 9-11.

Hertel, T. 1997. *Global Trade Analysis: Modeling and Applications*. Cambridge: Cambridge University Press.

Hertel, T, H.-L. Lee, S. Rose, and B. Sohngen. 2009. "Modeling Land-use Related Greenhouse Gas Sources and Sinks and their Mitigation Potential." In *Economic Analysis of Land Use in Global Climate Change Policy*, T. Hertel, S. Rose, and R. Tol eds, pp. 123–154. London, England: Routledge Publishing.

IPCC. 2006. "2006 IPCC Guidelines for National Greenhouse Gas Inventories." Prepared by the National Greenhouse Gas Inventories Programme. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe, eds. IGES, Japan.

——. 2007. "Climate Change 2007 – Mitigation of Climate Change". Contribution of Working Group III to the Fourth Assessment Report of the IPCC, Intergovernmental Panel on Climate Change (IPCC), B. Metz, O. R. Davidson, P. R. Bosch, R. Dave, and L.A. Meyer, eds. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lee, H.-L. 2007. An Emissions Data Base for Integrated Assessment of Climate Change Policy Using GTAP. GTAP Resource No. 1143, *Center for Global Trade Analysis*. Purdue University, West Lafayette, IN.

Lee, H.-L., T. W. Hertel, S. Rose, and M. Avetisyan. 2009. "An *Integrated Global Land Use Data Base for CGE Analysis of Climate Change Policy Options.*" In *Economic Analysis of Land Use in Global Climate Change Policy*, T. Hertel, S. Rose, and R. Tol eds, London, England: Routledge Publishing.

McDougall, R., and A. Golub. 2007. "GTAP-E Release 6: A Revised Energy-Environmental Version of the GTAP Model." GTAP Research Memorandum No. 15, *Center for Global Trade Analysis*. Purdue University, West Lafayette, IN, USA.

Otto, V. M., and J. Reilly. 2008. Directed technical change and the adoption of CO_2 abatement technology: The case of CO_2 capture and storage. *Energy Economics* 30(6): 2879–2898.

Reuters, T. 2009. Japan industry unites against carbon tax. Reuters. Dec. 7, 2009. http://uk.reuters.com/article/idUKTOE5B609U20091207. Accessed 27 May, 2011.

Rose, S., *et al*. In press. "Land-based mitigation in climate stabilization," *Energy Economics.*

Rose, S. 2011. Agricultural Non-CO_2 Greenhouse Gas Abatement Supplies for Global CGE Modeling. GTAP Technical Note. *Center for Global Trade Analysis*. Purdue University, West Lafayette, IN.

Rose, S., and H.-L. Lee. 2009. "Non-CO_2 Greenhouse Gas Emissions Data for Climate Change Economic Analysis." In *Economic Analysis of Land Use in Global Climate Change Policy*. Thomas W. Hertel, Steven K. Rose, S. Richard, and J. Tol eds, pp. 89–120. London, England: Routledge Publishing.

Seo, S. N. 2010a. A Microeconometric Analysis of Adapting Portfolios to Climate Change. *Applied Economic Perspectives and Policy* 32(3): 489–514.

——. 2010b. Is an integrated farm more resilient against climate change? A microeconometric analysis of portfolio diversification in African agriculture. *Food Policy* 35: 32–40.

Sinclair, KD, and R. Webb. 2005. Reproductive rate in farm animals: strategies to overcome biological constraints through the use of advanced reproductive technique. In *Yields of Farm Species: Constraints and Opportunities for the 21st Century*. R. Sylvester-Bradley, and J. Wiseman eds, pp. 51–87. Nottingham University Press, UK.

Smith, P., *et al*. 2008. Greenhouse gas mitigation in agriculture. *Philosophical Transactions of the Royal Society B (Biological Sciences)* 363: 789–813.

United Nations Food and Agriculture Organization (FAO). 2009. State of Food and Agriculture – Livestock in the balance. FAO, Rome.

United States Environmental Protection Agency 2006a. *Global Anthropogenic Non-CO_2 Greenhouse Gas Emissions: 1990 – 2020.* Washington, D.C.: Office of Air and Radiation, United States Environmental Protection Agency.

——. 2006b. *Global Mitigation of Non-CO_2 Greenhouse Gases*. Washington, D.C.: United States Environmental Protection Agency. Available at http://www.epa.gov/nonco2/econ-inv/international.html.

van Ham J., A.P.M. Baede, L.A. Meyer, and R. Ybema (eds.). 2000. Non-CO2 Greenhouse Gases: Scientific Understanding, Control, and Implementation. *Proceedings of the Second International Symposium, Noordwijkerhout, The Netherlands, 8-10 September 1999*. Springer, pp 604.

van Ham J., L.J.H.M. Janssen, and Rob J. Swart (eds.). 1994. Non-CO2 Greenhouse Gases: Why and How to Control? Proceedings of an International Symposium, Maastricht, the Netherlands, 13-15 December 1993. Springer, pp 562.

Weyant, J.P., F. de la Chesnaye, and G. Blanford. 2006. Overview of EMF-21. *The Energy Journal*. Special Issue No. 3, (Multigas Mitigation and Climate Policy).

Wirsenius, S. 2003. Efficiencies and biomass appropriation of food commodities on global and regional levels. *Agricultural Systems* 77: 219–255.