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Modeling the Effects of Pasture Expansion on Emissions from Land-Use Change

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Keywords
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Abstract

We present a global agricultural greenhouse gas model that assesses emissions from land-use change. In addition to evaluating shifts in and out of crop production, we develop a pasture model to assess extensification and intensification of global livestock production based on herd size and stocking rate. We apply the model to a scenario that introduces a tax on methane emissions from cattle in the United States. The resulting expansion of pasture in the rest of the world leads to substantially higher emissions than without the tax. The yearly average emissions from the tax are 260 metric tons of CO_2-equivalent.

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JEL Code

Q15, Q17, Q18, Q54

1. Introduction

The passage of the American Clean Energy and Security (ACES) Act of 2009 in the House of Representatives in July 2009 and negotiations at the 15th Conference of Parties of the United Nations Framework Convention on Climate Change in Copenhagen in December 2009, which marked the beginning of a post-Kyoto climate policy framework, are both examples of a changing political and regulatory environment in the U.S. and globally. Major opportunities are opened to the world agricultural sector if offset provisions are part of climate change policies. Given the offset credit provision in ACES and the climate policy framework potentially arising from Copenhagen and future climate change conferences, it is important to understand the effects of modified agricultural production on land-use change and carbon emissions. The implementation of large-scale agricultural policies such as offset options or taxes is often prone to unintended consequences.

In this paper, we introduce a global agricultural greenhouse gas model that calculates emissions from land-use change in a dynamic framework taking idle cropland into account. In addition to evaluating changes in global crop area, we develop a pasture model to assess extensification and intensification of livestock production based on herd size and stocking rates. We apply the model to a policy scenario that introduces a livestock tax on methane emissions from cattle in the United States. The tax was proposed in the fall of 2008 because of concerns about greenhouse gas emissions but was not introduced.

A recent article by Searchinger et al. (2008) examined the impact of U.S. biofuel policy on world carbon emissions. In the article the authors assumed that yields remained at baseline levels in the biofuel expansion scenario. As a result, grain required for biofuels could only be produced on new acres that were brought into production. This assumption set up a trade-off between food and fuel production on the one hand and the environmental consequences of the conversion of new lands into agricultural uses on the other. A follow-up paper by Dumortier et al. (2009) showed that the Searchinger et al. results are highly sensitive to the constant yield assumption. Higher land productivity, possibly brought about because of biofuel-induced price increases, can offset the carbon released from the conversion of new lands. The intuition here is that the increased productivity is assumed to be permanent and therefore of benefit for multiple years, whereas the carbon cost associated with one-time conversion is temporary.

The 10% tax we use in this paper can be considered a productivity loss of the same magnitude. The tax can be considered a cost increase that is brought about by reduced productivity. Our results trace out the environmental implications of a permanent change in the productivity of the beef herd in one country on world carbon emissions after allowing for market changes in other countries. The results are reversible and can also be used to examine the environmental implications of a 10% productivity gain. A productivity gain might be achieved through additional research, and a productivity loss could be driven by a consumer or regulatory environment that moves the industry away from baseline productivity levels. As such, the results can be generalized to understand the implications of a wide variety of possible developments.

The analysis is done in two parts. First, we use the Center for Agricultural and Rural Development (CARD) Agricultural Outlook Model (this model is sometimes referred to as the FAPRI model) to project the effects of the livestock tax on world agricultural production. This is the model that was used by Searchinger et al 2008, and by Fabiosa et al forthcoming, however it is updated in this paper to incorporate a more detailed specification of Brazilian agriculture. As we will explain below, Brazil is modeled at the sub-national level taking local production cost, yield, livestock, and pasture into account. Once the global impact on crop area, herd size, and pasture is calculated, a greenhouse gas model is used in a second step to assess the emissions from land-use change. Those emissions are contrasted with emissions directly attributable to livestock activity such as enteric fermentation and manure management.

Worldwide GHG emissions under the U.S. cattle tax scenario are higher than under the baseline. Reduced production in the United States is in part offset by an increase in production in the rest of the world, especially in Brazil. Furthermore, the livestock production systems in those offsetting countries are based on relatively extensive livestock production systems and hence an expansion of pasture into natural vegetation.

Our study makes three contributions to the literature. First, a model for Brazilian agricultural activity is presented. This is necessary to better understand the land-use impacts due to agriculture in a country that is important for agriculture and for the terrestrial carbon balance. Second, a greenhouse gas model that tracks emissions from land-use change is presented and used. A pasture component of this GHG model is introduced to understand extensification and intensification of global livestock production. This study fills a gap in the literature by linking pasture, stocking rate, and herd size to land conversions. Third, we show that policies that are likely to affect land use need to be thoroughly assessed before implementation. The carbon content of a hectare of native vegetation is very high and hence small changes in land use can have a large impact on emissions. The results suggest that it is important from a GHG perspective to focus on agricultural policies that reduce conversion of land from native vegetation or which increase the productivity of existing sting crop or livestock production systems.

2. Previous Work

The expansion of livestock and pasture is becoming an increasingly pressing issue, especially in view of a growing human population and increased demand for livestock products (World Bank 2010). Population growth, urbanization, and increasing income levels are key drivers of livestock product demands. The intensification of grazing systems is expected, especially in Latin America (World Bank 2010). It is estimated that developing countries in which most of the livestock expansion takes place will intensify their livestock production (FAO 2006).

Brazil because of its large cattle herd (around 200 million head) and vast areas of tropical rainforest, which contain large amounts of carbon deserves special attention. In the Brazilian province of Mato Grosso, pasture remains the dominant use of land, after forest clearing (Morton et al. 2006). A low stocking rate of 0.5 head/ha attenuates the problem of pasture expansion in the Legal Amazon (Chomitz and Thomas 2003). Our own calculations for Brazil indicate stocking rates of 0.6–0.7 for the 1997 to 2000 period in the Legal Amazon reaching 0.93 by 2009. Mertens et al. (2002) point out three purposes for pasture in Brazil that accelerate its deforestation: pasture provides feed for livestock; Brazilian land policies are such that pasture is the easiest way to claim ownership over land; and grazing avoids rapid forest re-growth and thus increases land value.

Wassenaar et al. (2007) develop a spatial and temporal model framework to analyze the expansion of pasture into forest in Latin America. The possible land uses are forest, pasture, cropland, and shrub. Our model adds idle cropland/set-aside as a category to this framework, as we will further discuss later. The Wassenaar et al. analysis predicts that, on average, 76% of deforested land will become pasture. This finding highlights the importance of including livestock expansion and pasture in the modeling framework.

The next section presents the economic model and greenhouse gas model used in our analysis. We outline the assumptions and parameters required to run the model. Section 3 reviews the results in terms of agricultural production from the baseline and the cattle tax scenario. Section 4 presents the results of the scenario in terms of greenhouse gas emissions. In this section, we calculate emissions from enteric fermentation and manure management and contrast them with emissions from pasture expansion. The last section concludes the paper and provides an outlook on future research.

3. Model

Our analysis is based on two components. The economic part uses the CARD Model developed at Iowa State University to provide us with data of agricultural production, for example, commodity prices, crop area, livestock size, and biofuel production, over a specified time period (2009 to 2023 in our case). The second part consists of a greenhouse gas (GHG) model, which takes the output from the CARD Model and calculates the emissions associated with land-use change. The output from the CARD Model also serves as a basis for calculating emissions from enteric fermentation and manure management. A simplified model structure can be found in Figure 1.

The CARD Model is used to project agricultural supply, utilization, and prices in 35 countries and world regions over a specified time period. Smaller countries are grouped in aggregate regions so that the CARD Model is global in scale. This global scale makes it possible to calculate GHG emissions from land-use change and agricultural production in a way that accounts for leakage. The non-spatial, partial equilibrium model covers 13 crops and three major livestock categories (cattle, swine, and poultry) as well as the biofuel and dairy industries. Based on historic data and agro-economic relationships, the model captures the competition for land among crops, that is, acreage for one crop depends also on the prices and return of other crops. The model solves for a market clearing world price and takes macroeconomic variables such as population growth and policy parameters, for example, price supports or import tariffs, into account. The livestock sector is a sub-model, and the economic decisions are based on the flow variables (slaughter) instead of the stock variables (herd size).

The structure of the CARD Model has been described in detail in previous publications (Searchinger et al. 2008, Hayes et al. 2009). In what follows, we will focus on the Brazil component of the model. Note that the general model was used by Searchinger et al. to calculate carbon emissions incurred by corn ethanol due to land-use change. Furthermore, the CARD Model is utilized by U.S. policymakers to evaluate the effects of policy on agricultural production and prices.

As previously mentioned, CARD possesses a regional Brazilian model that takes local production cost, cropland allocation, and pasture into account. The latter is combined with livestock projections to find endogenously determined stocking rates.

Brazilian agricultural production has experienced an impressive expansion in recent years. Because of its size and geographical location, Brazil encompasses widely varying ecosystems, ranging from grassland and crops associated with temperate climates in the South to tropical forests in the North and semiarid areas in the Northeast. The different regions also present enormous developmental disparities in terms of infrastructure, logistics, and strategies available to increase production. Thus, while rapid expansion of production of some commodities may only be achieved by taking area away from other agricultural activities in land-constrained regions, increases in area used by all activities may be observed in other parts of the country; which points to distinct dynamics in the competition for land across space. Environmental (both local and global through the emission of GHGs), social, and economic impacts hinge critically on the nature of these land-use changes. Therefore, it is becoming increasingly important to recognize the spatial dimension of the agricultural expansion as its impacts are likely to be dependent on the way in which it occurs as well as on the resources of the location in which production takes place.

A spatially disaggregated partial equilibrium model of Brazilian agricultural production was constructed at the regional level, incorporating major crops, biofuels, and livestock interacting and competing for agricultural resources, in particular, land. Outputs from the model include projections of production and utilization variables, and the amount of land allocated to the activities considered. On the crops side, we consider corn (first and second crops), the soybean complex (including soybean meal, soybean oil, and biodiesel), the sugarcane complex (including sugar and ethanol), rice, cotton, and dry beans (multiple cropping depending on the region). The modeled animal products are beef, pork, poultry, and dairy. In terms of land allocation, and as will be discussed with more detail in the next section, the area used by a given activity depends on its expected real returns in comparison to expected returns of activities that compete for the resource. The strategy for modeling livestock activities closely follows that utilized in the international livestock model of CARD, with the additional layer of explicitly modeling land used by beef and dairy production. Since not all the regions considered are equally suited for different activities, the competition for land is contingent on the location. As such, not all activities compete with each other with the same intensity in all regions.

Through the use of spatially disaggregated information on historical production activities and natural resource availability, the model is able to determine the relative profitability of different activities at the local level, which as mentioned will drive regional supply curves for relevant commodities and their associated land use. For this modeling effort, Brazil is divided into six regions: South, Southeast, Central-West Cerrados, North-Northeast Cerrados, Amazon Biome, and Northeast Coast, to take differences in land constraints such as agricultural activity and legal land reserves into account. Four of the six regions consist of whole states whereas the state of Mato Grosso is allocated to two regions to take the boundary to the Amazon Biome into account. The model is able to capture the regional differences in terms of capabilities and consequences of the expansion, so that the impacts of land-use changes derived from increasing demand for agricultural products can be more precisely established. Since the goal of the model is to be able to project land use (and changes) at a regional level, production functions are modeled at the spatial scale. However, the demand side of the model is built at the aggregate (country) level. The land-use projections represent the largest departures from other models in the CARD Model system. Endogenous prices drive production and consumption equations in the model for crops, livestock, and dairy products. A solution for the model is a set of prices such that supply equals demand in all markets.

The supply of a crop i in year t (S_{it}) comes from two main sources, namely, production Y_{it} and beginning stock BS_{it}. Beginning stocks are not explicitly modeled but are derived from the ending stocks (*ES*) of the previous period. Ending stocks are modeled at the country level as a demand component.

Production of crop *i* in region *j* at time *t* is given by $Y_{ijt} = A_{ijt} * y_{ijt}$, for $i = 1, 2, ..., I$, and $j = 1, 2, ..., 6$. A_{ijt} and y_{ijt} denote the area planted and yield of crop *i* in region *j* in year *t*, respectively. Yields for each crop and region are projected, including a time trend, returns to the crops (intensification), and area used for production of major competing activities (extensification).

Two different procedures are followed to project the area allocated to agricultural activities. First, for crops determined not to compete for land resources during the main growing season for major crops, the area is projected (as in the other CARD Model) directly using the equation described below. Second, the area of activities (crops and pasture) competing for land in space and time is projected following a two-step approach. The first step determines the total amount of land to be used by these activities combined. The second step parcels that area out to the different activities.

For crops or activities assigned as not in competition, area planted depends on its own expected real returns $\left(R_{ijt}\right)$, expected returns of activities that compete for the use of land $\left(R_{-ijt}\right)$, and the area planted to the crop in the previous period as follows:

$$A_{ijt} = A_{ijt}\left(A_{ij,t-1} R_{ijt}, R_{-ijt}\right).$$

Time trends and/or other relevant policy variables are also specified in this equation. Expected real returns for an activity is modeled as

$$R_{ijt} = E\left(p_{ijt}\right)\hat{y}_{ijt} - Cost_{ijt},$$

where $\hat{y}_{ijt}$ is the expected (trend) yield for the crop in region *j* and year *t*. $E\left(p_{ijt}\right)$ is the expected real price for the crop in region *j*, which in turn is a function of the country-level expected price $E\left(p_{it}\right)$ for year *t*. To reduce the number of prices needed to be solved, we invoke a spatial arbitrage argument and assume the prices of different regions are related to a country price as $p_{ijt} = f_{ij}\left(p_{it}\right)$. That is, $E\left(p_{ijt}\right) = f_{ij}\left(E\left(p_{it}\right)\right)$ which holds because we assume the function f_{ij} to be linear in prices.

As mentioned above, for activities assigned to the second procedure, a two-step approach is followed. The first step determines the total amount of land to be used in the period based on expected returns and the potential availability of land using the following equation:

$$A_{jt}^{ag} = A_j^T m_j\left(\overline{r}_{jt}\right),$$

where A_{jt}^{ag} is the land that will be used for agriculture (including pastures) in region *j*, and year *t*, A_j^T is the potential amount of land for agricultural activities in region *j*, and $m_j\left(\overline{r}_{jt}\right)$ is the share of that potential land that will actually be used depending on aggregate expected returns in the region and year $\overline{r}_{jt}$ .These agriculture-wide expected returns evolve with time based on the following formula:

$$\overline{r}_{jt} = \overline{r}_{jt-1} * \sum_{i=1}^{I} \left(\frac{\tilde{A}_{ijt}}{A_{jt}^{ag}} \frac{r_{ijt}}{r_{ijt-1}} \right),$$

which indicates that the return it evolves based on a weighted average of the change in returns of the activities considered. The variable $\tilde{A}_{ijt}$ is defined in the second step, which follows closely the method published by Holt (1999). It consists of parceling that area out to the different activities, based on own returns and returns of competing activities with the restriction that the sum of the shares needs to add to one. Hence, for these activities we have $\tilde{A}_{ijt} = A_{jt}^{ag} * v_{ijt}$, where v_{ijt} is the share of activity *i* in region *j* and year *t*, with $\sum_{i=1}^{I} v_{ijt} = 1$ for all *j* and *t*.

For each crop in each region and year, production is thus projected as

$$\hat{Y}_{ijt} = \tilde{A}_{ijt} * \hat{y}_{ijt},$$

and the country-level area and production of a crop *i* are obtained by summing across regions, that is, $\tilde{A}_{it} = \sum_{j=1}^{6} \tilde{A}_{ijt}$ and $\hat{Y}_{it} = \sum_{j=1}^{6} \hat{Y}_{ijt}$. Total supply available for that crop would then be estimated as $\hat{S}_{it} = \hat{Y}_{it} + \hat{B}S_{it}$.

The demand for crops is in general separated into three components: (a) consumption, (b) ending stocks, and (c) net exports as follows:

$$D_{it} = C_{it} + ES_{it} + NE_{it}.$$

Depending on the crop considered, consumption may be final, or it may be derived from the demand of other production processes (e.g., soybeans and sugarcane). For some products, such as corn, domestic demand is further disaggregated into food and feed consumption.

An equilibrium is reached when a set of prices is found that solves $S_{it} = D_{it}$ for all crops/products and years. That is, equilibrium is found when

$$S_{it} = Y_{it} + BS_{it} = C_{it} + ES_{it} + NE_{it} = D_{it}$$

holds for all *i* and *t*.

As in the crops section, whereas the supply side of the livestock model is divided into six regions, the demand is modeled at an aggregate level. The products modeled are broilers, dairy, pork, and beef. The structure of the supply side of livestock depends on the product being modeled. For the case of poultry, production is modeled directly. For these products, output levels are projected based on their regional prices and costs of production (mostly feed costs). For beef, dairy, and hogs, both the stocks of animals and production levels consistent with these stocks are modeled. A slightly more involved structure is used for both beef and pork projections.

The stocks of cattle and hogs are mainly driven by the modeled stocks of cows and sows. Given these stocks, and the projected birth rates, the crop size (calves and piglets) can be obtained. Adult animals not part of the breeding herd are allocated to an "other" (cattle or hogs) category. Death and slaughter rates of the different categories are used to calculate the beginning stocks the following year. The supplies of beef and pork meat are calculated by multiplying the number of animals slaughtered (given by stocks and slaughter rates) by the average slaughter weight. Ending stocks of meat are fixed at zero.

The modeling of the stock of beef cows in the Brazil model warrants some additional explanation, as it differs from the structure used in other countries and is key to our analysis. The evolution of the beef cattle herd is (in the Brazil model) linked to the area of pasture available, as beef production is the largest user of pasture. This is a departure from the other models in the system, which do not model pasture directly. A link between pasture availability and the size of the cattle herd is introduced by directly modeling the stocking rate (number of cows per hectare of pasture). Drivers of this stocking rate include returns to beef production and the lagged stocking rate. Thus, if pasture area is reduced (e.g., because of competition from crops), the cattle herd will get a signal to contract (fewer cows will result in fewer calves and less “other cattle” in the next periods). Pasture expansion will let the herd grow more quickly.

The demand component of the livestock sector is similar to that of the crops side, in that it is separated into domestic consumption and net export demand. The market equilibrium conditions are obviously the same as those for the crops side. A vector of prices needs to be found for each year such that country-level supply equals demand.

Let s_t be the stocking rate in period *t*, ES_t^b, ES_t^d, ES_t^{ot} denote ending stocks of beef cows, dairy cows, and other cattle, respectively, and A_{t-1}^p is pasture area. Thus

$$s_t = \frac{BS_t^b + BS_t^d + BS_t^{ot}}{A_{t-1}^p} = s_t^b + s_t^d + s_t^{ot}$$

where

$$s_t^b = \frac{ES_t^b}{A_t^p} = a * t^{\beta_0} \left(s_{t-1}^b\right)^{\beta_1} \left(r_t^b\right)^{\beta_2}$$

and where r_t denotes returns. In log form,

$$\ln(ES_t^b) = a' + \ln(A_t^p) - \beta_1 \ln(A_{t-1}^p) + \beta_0 \ln(t) + \beta_1 \ln\left(ES_{t-1}^b\right) + \beta_2 \ln\left(r_t^b\right).$$

The outputs used from the CARD Model are livestock herd size, cropland allocation, and yield. In addition, the Brazilian model includes pasture allocation. Spatial heterogeneity places an important role in calculating GHG from land-use change and agricultural production. Biomass carbon stocks, soil organic carbon, and livestock emissions depend on land type, ecosystems, and temperature. Because of spatial variation in the biomass and soil carbon stock, it is necessary to know where crop expansion takes place. The output of the CARD Model is at the country or regional level and not at the state level. To capture spatial heterogeneity, large countries such as China, India, and the United States are subdivided into their states, which results in 518 spatial units globally. Before being fed into the GHG model, the output data from the CARD Model needs to be transformed.

Given the crop data for a particular country, we need to know where the different crops are located at the sub-national level. For this purpose, the country crop area from the CARD Model is disaggregated with the help of the FAO Agro Maps database, which provides the information of the location by crop and by country of intra-country crop distribution. To determine the effect of agricultural expansion, it is assumed that regions that have a high proportion of agricultural activity are more likely to see a cropland expansion because the infrastructure is already in place. For example, suppose a country has two states, A and B. If the allocation of wheat area in that country is 80% in state A and 20% in state B, then an increase of 100 hectares would be allocated as 80 ha in state A and 20 ha in state B. Hence, the proportion of cropland in a particular state within a country is fixed.

We are interested in the dynamics of agricultural land that includes pasture for cattle. With the exception of Brazil, the pasture area in other countries is not directly reported from the CARD Model but can be calculated via the herd size of cattle and the stocking rate. Hence, calculating pasture expansion proves to be more complicated. In the scenario analyzed, the change in beef cow numbers is assumed to be the only cause of additional pasture. Note that not all beef cows are on pasture but some are raised in an industrial production context or a mix of industrial and pasture. The Intergovernmental Panel on Climate Change (IPCC) reports the following pasture usage for beef cows: North America (81.5%), Western Europe (32.0%), Eastern Europe (20.0%), Oceania (91.0%), Latin America (99.0%), Africa (95.0%), Middle East (79.0%), Asia (50.0%), and Indian Subcontinent (22.0%). The Global Livestock Production and Health Atlas (GLiPHA) of the Food and Agriculture Organization (FAO) is used to determine the livestock distribution within a country. The approach chosen is very similar to the one used for crops.

The Food Insecurity, Poverty and Environment Global GIS Database provides us with a grid map of pasture occurrence. The FAO assumes that 60% of global pasture is used for grazing. Knowing the pasture area available in each of the 518 units and the number of beef cattle, we can calculate an implied stocking rate. We use 2007 as the year of reference for the implied stocking rate. In the model, constant pasture expansion elasticity with respect to the total cattle numbers is assumed, that is, a cattle herd expansion of x% causes an increase in the stocking rate of $\beta \cdot x$% where $\beta \geq 0$. On ce the total cropland and total pasture within a spatial unit are determined for every year, both amounts are summed up to derive the amount of agricultural land. Note that this transformation is not necessary for Brazil because pasture data is readily available.

The GHG model results presented here are driven by land-use change. However, we are also able to evaluate emissions from agricultural production, especially from livestock management. The land-use change determines the emissions from shifts into and out of agricultural land, which consists of cropland and pasture. In the second part, agricultural production measures methane and nitrous oxide emissions attributable directly to agricultural activities such as crop and livestock management. Recall that given the context of our analysis, we are interested in the methane and nitrous oxide emission savings in the U.S. due to the livestock tax and, hence, we focus on livestock and do not include crop emissions such as mineralization and leaching/run-off. The impact of the proposed methane tax on crops is very limited, and the effect on crop area and emissions is negligible.

Land-Use Dynamics and Carbon Stock Change

Land-use change is seen to be the biggest problem and challenge in assessing GHG emissions from agriculture. The expansion of cropland into grassland and forests causes the release of carbon stored in soil and biomass and is referred to as direct land-use change. Indirect land-use change occurs if existing cropland, originally used for food and/or feed production, is diverted to an alternative use, for example, growing stock for biofuels. This causes indirect land-use change because part of the lost food and/or feed production will take place somewhere else. It is very difficult to measure land-use change explicitly because the only way to measure it is through remote sensing, that is, satellite imagery. Consistent time-series data from remote sensing are currently not available on a global scale.

The calculations of land-use-change related emissions are accomplished in two steps. First, the land-use dynamics need to be calculated based on the output of the CARD Model. In a second step, carbon emissions based on land dynamics and biophysical conditions are computed. The two sources/sinks of carbon are biomass and soil.

To calculate land-use dynamics, six categories of land are considered: forest, shrubland, grassland, set-aside, cropland, and pasture. However, as mentioned before, the last two categories are summed up to form agricultural land. Table 1 represents the possible land transitions (yes/no) and the associated change in the carbon stock, which can be positive (+), negative (-), or no change (○). Note that no change in the carbon stock is an assumption to simplify the model. Even when cropland remains cropland and pasture remains pasture, small carbon changes can be seen in reality.

Once the amount of agricultural land necessary per year and the spatial unit is determined, land dynamics are calculated with MATLAB. A schematic representation of this process can be found in Figure 2. We assume that the idle cropland at the beginning of the simulation period (2000) is determined to be 40% of the pasture land, that is, the land that is not used for grazing. For example, it turns out that in parts of Africa, large areas were deforested during the colonization period. We make the assumption that in every country, there are pasture areas that can be converted into cropland. Because we are interested in the difference between two scenarios and not in the absolute value, we assume that we have a fixed stock of native vegetation at the beginning of the simulation period. By comparing the two scenarios, we calculate how much of the native vegetation was used up.

The most important feature of the model is the tracking device for marginal agricultural land coming into and out of set-aside. It is fair to assume that agricultural land that comes out of production last in the case of a decrease in agricultural land is the first land that comes into production if more land is needed. It is important to keep track of the years and hence the amount of carbon sequestered of the set-aside land. In the present model, a MATLAB code was written to take land that was last taken out of production and put it back into production first. This land has been sequestering carbon for the least amount of years compared to the rest of the set-aside land. Only when all set-aside land is used do native vegetation systems such as forest and shrubland come into production. In the U.S. model, the initial Conservation Reserve Program or other set-aside land is based on the 2007 Agricultural Census and is assumed to have been sequestering carbon for 10 years.

For each spatial unit, the difference from the previous year's agricultural land is calculated. If cropland comes out of production, it goes into the pool of set-aside and starts sequestering carbon. The algorithm checks whether sufficient idle land is available or not if agricultural land increases. If sufficient agricultural land is available, idle land comes into production based on the last in (idle land), first out. Only when idle cropland is not sufficient does it go into native vegetation (see Figure 2).

Biomass in forests is determined by the ecological zone, the type of native vegetation, and the continent. The IPCC guidelines give the average above-ground biomass (in tons of dry mass per hectare) and the shoot-to-root ratio. A default factor of 0.47 tons of carbon per ton of dry matter is used to calculate the biomass in CO_2-equivalent. This category also includes forgone carbon sequestration due to land-use conversion. To determine the forgone carbon uptake, one must know the forest's age distribution. In most cases this information is not available and hence a 50/50 distribution of trees younger and older than 20 years is assumed. It turns out that the age distribution has a rather small impact on the forgone carbon uptake because younger trees sequester at a higher rate per year but for a shorter period (until they are over 20 years) whereas older trees sequester at a lower rate for a longer period.

To determine which ecological zone is affected by a particular crop, the distribution of agricultural production was determined using the FAO Global Spatial Database of Agricultural Land-Use (Agro Maps) on a first-level administrative unit scale. For groups of countries, data from the U.S. Department of Agriculture's Production, Supply & Distribution (PS&D) database was used to determine production coefficients. Then, a GIS map of native vegetation was combined with the map of ecosystems (global ecological zones) to establish the type of native vegetation where an agricultural activity takes place. A map of native vegetation was used to evaluate whether the undisturbed land in a particular region is forest, shrubland, or grassland. Together with the map of ecosystems, this helps to map the default values of the IPCC so they match with the region of interest.

If land is converted to cropland, carbon stored in soils (soil organic carbon, or SOC) is released into the atmosphere. The change in the amount of SOC depends on factors such as climate region, native soil type, management system after conversion, and input use. A global soil map (FAO Soil Map) was obtained that subdivides soil into three large categories (20 t/ha, 40 t/ha, and 80 t/ha). As mentioned before, the conversion is assumed to be from forest, shrubland, grassland, and set-aside to agricultural land, that is, cropland and pasture. It is assumed that cropland is managed with medium input and full tillage. The top 30 cm of carbon is supposed to be lost after initial cultivation, and once taken out of cultivation the land reaches the new equilibrium (initial stage) in 20 years.

Agricultural Production

Emissions from agricultural production include enteric fermentation, manure management, and agricultural soil management. The calculations are based on the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, tier 1 method (IPCC 2006). The necessary equations can be found in that publication and are not reproduced here.

Enteric fermentation takes place in the digestive system of ruminant animals. In order to estimate CH_4 emissions from enteric fermentation, default emission factors from the 2006 IPCC Guidelines are used. The IPCC values for cattle distinguish only between *Dairy* and *Other Cattle*. In the present model, it is assumed that beef cows are equivalent to the *Other Cattle* category. Methane emissions from swine are very small. The data necessary to calculate the methane emissions are the number of head in the country of interest and the emission factors (IPCC 2006).

Methane emissions from manure management depend on the temperature the animal is exposed to and the continent. Given the livestock distribution within a country or group of countries and the data from weather stations on the average annual temperature, default manure management emission factors for cattle and swine are used to calculate the emissions. Note that the temperature remains constant over the projection period.

Nitrous oxide emissions from manure management depend on the type of manure management system, the nitrogen (N) excretion rate, and the total animal mass. The default N excretion rate is multiplied by the typical animal mass to obtain the annual N excretion. The nitrous oxide emissions depend on the annual N excretion but are also influenced by the type of manure management system. IPCC provides emission factors and usage shares by world region for the following manure management systems: anaerobic lagoon, daily spread, deep bedding, deep pit, digester, dry lot, liquid/slurry, pasture/range/paddock, and solid storage. Note that the category *burned for fuel* is ignored. Furthermore, it is assumed that all manure ends up on pasture and cropland as organic manure at some point in time. We apply the described method to countries other than the United States. For the U.S., the Environmental Protection Agency (EPA) inventory report (EPA 2007) provides detailed system usage for every state.

4. Scenarios

In this section, we present the results in terms of agricultural production from the baseline 2009 (Baseline) and the livestock tax in the United States (*Tax*). The crops included are barley, corn, oats, rice, rapeseed, rye, soybeans, sugarcane, sugar beet, sunflower, and wheat.

The motivation for the *Tax* scenario was a proposal for a methane tax made by the EPA in the fall of 2008. According to the 2010 EPA GHG Inventory (EPA 2010), agriculture is responsible for approximately 6% of total U.S. GHG emissions, or 427.5 mt of CO_2-equivalent in 2008. About 33% of emissions from agriculture can be attributed to methane emissions from enteric fermentation. This number is also valid on a global scale. The idea behind the EPA tax, which was actually nothing more than an advance notice of proposed rulemaking, was to bring down those emissions. Though the tax was not imposed, it serves as an example of what could happen to GHG emissions globally if policy were introduced unilaterally.

The *Tax* scenario analyzed with the CARD Model assumes a 10% tax on fed steer prices. This leads to a reduction in U.S. beef cows of 21%, or 17.43 million head, by the year 2023. The reduction in beef cows is offset by increased production elsewhere. Table 2 illustrates this effect by comparing U.S. and Brazilian beef cow numbers before and after the tax. Brazilian beef cow production increases by 3.71%, or 8.61 million head. The increase in Brazil is much higher than the global average (not including the U.S.), which is only 1.4%, or 11.5 million head. We show in subsequent sections that the increase in Brazil plays a pivotal role in the calculations of carbon emissions due to land-use change. Figure 4 shows the increase in Brazilian pasture in the three regions that are responsible for a 94% cattle increase. Note that region 4 includes the Legal Amazon. This is of particular importance because the Legal Amazon is rich in biomass carbon.
As mentioned in the introduction, the calculation of the pasture area in countries other than Brazil relies heavily on the assumption about the stocking rate elasticity with respect to cattle growth. The effects of different stocking rate elasticities are analyzed without changing the out-

put obtained from the CARD Model. This feature will become important for analyzing the *Tax* scenario. The growth rate of the stocking rate (intensification versus extensification) has a significant impact on emissions from land-use change due to pasture expansion. So within the *Tax* scenario, different pasture growth rates will be analyzed in order to get a complete picture of the effects of a U.S. livestock tax.

Using FAO pasture and cattle data between 1961 and 2007 and running a simple ordinary least squares regression with pasture as the dependent variable and cattle as the independent variable reveals an elasticity of 0.7 and 0.87 for Europe and Asia, respectively (t-stat: 4.75 and 49.93). For Brazil, the stocking rate elasticities implied by the model average around 0.25 for Brazil as a whole and the Legal Amazon. In the following section, we present our detailed results, with an elasticity of 0.5 used for the rest of the world. Based on our analysis of the FAO data, this is probably at the lower bound. Increasing this elasticity will not change the results significantly because Brazil is a major contributor to GHG emissions and is unaffected by the changing elasticity. This is true because the Brazil model explicitly accounts for pasture utilization rates.

5. Results

The *Tax* scenarios are presented with respect to the baseline because only the difference in emissions is of interest in the case of policy evaluations. If the purpose of the livestock tax in the U.S. is to reduce GHG emissions, then pasture expansion due to increased production elsewhere needs to be taken into account. Before the pasture expansion is analyzed, the effect on emissions from agricultural production in the U.S. and elsewhere is presented. In our model, emissions from agricultural production are modeled separately and are not influenced by land-conversion decisions and hence are independent of the inclusion of pasture and the stocking rate elasticity. For this analysis, we do not include nitrous oxide emissions from agricultural soil management but focus on emissions from livestock.

By 2023, the emissions from enteric fermentation, manure management, and organic amendments to cropland and pasture decrease by 20.6%, or 27.3 mt of CO_2-equivalent, as represented in Table 3. Those are the numbers attributable to beef cows only. We report the mean emissions over the projection period as well as the emissions in the year the long-run equilibrium is imposed. Because beef numbers evolve gradually over time, the mean numbers are higher in case of a herd decrease, that is, in the U.S., and lower in the case of a beef cow herd increase. Whereas emissions in the U.S. decline as a result of the cattle tax, emissions in other countries increase because of expanded cattle production. Emissions from enteric fermentation in Brazil increase from 242.5 mt CO_2-equivalent to 251.1.7 mt CO_2-equivalent, or by 3.54%. This offsetting increase in emissions can be found in other countries as well; however, the total emissions from agricultural production are still lower in the case of the livestock tax if land-use change is not considered. The results reported in Table 3 are consistent with the idea of reducing emissions from enteric fermentation in the U.S. and the rest of the world via a methane tax. However, it also illustrates that those savings will be relatively low.

We now turn our attention to the land-use change component of the model, which takes pasture expansion into account. Table 4 shows the emissions associated with a stocking rate elasticity of 0, 0.5, and 0.75. As previously mentioned, Brazil is unaffected by this choice because pasture is directly calculated. Over the projection period from 2009 to 2023, most of the emissions come from pasture expansion in Brazil. If we assume the reference pasture elasticity to be 0.5, an average of 260.3 mt of CO_2-equivalent more is emitted per year as compared to the baseline. A change of the stocking rate elasticity to 0 or 0.75 does not change the direction of the results. Given the cattle increase in Brazil, coupled with the low stocking rate and the high carbon content, imposing a cattle tax in the U.S. does not reduce emissions globally. Even setting the stocking rate elasticity to 1, that is, the stocking rate in the rest of the world increases at the rate of the cattle increase and does not require more pasture, this would not make up for the emissions in Brazil.

A word of caution is needed concerning the emissions from pasture expansion, especially in Brazil. Given the literature previously mentioned (Worldbank 2010), it is possible that in the long run, we would see a change in grazing patterns to more landless livestock production systems. In addition, as has been shown in previous work, emissions from land-use change are very sensitive to the assumptions made. This is because the per hectare carbon stock of natural vegetation is relatively large compared to emissions from agricultural production alone (e.g., nitrous oxide emissions from fertilizer).

6. Conclusion

We present a greenhouse gas model that tracks land-use change and associated emissions from carbon release or sequestration. In addition, we introduce a pasture model that accounts for intensification and extensification of livestock. The model is applied to evaluate a rest-of-the-world livestock expansion caused by a cattle tax in the United States. We show that a GHG policy in the U.S., if not thoroughly assessed, can cause more harm than having no GHG policy.
It can be concluded that policies aimed at reducing land-use change are a “low hanging fruit” because they are very effective at avoiding emissions. Policy options that reduce land-use change, such as intensification (including stocking rate increases), should be an effective way to reduce GHG if applied globally. Furthermore, leakage is an important problem that should be analyzed when evaluating policy options.

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Table 1. Land Transition Matrix

From\to	Forest	Shrubland	Grassland	Set-aside	Cropland	Pasture
Forest	Yes/○	No	No	No	Yes/-	Yes/-
Shrubland	No	Yes/○	No	No	Yes/-	Yes/-
Grassland	No	No	Yes/○	No	Yes/-	Yes/-
Set-aside	No	No	No	Yes/+	Yes/-	Yes/-
Cropland	No	No	No	Yes/+	Yes/○	Yes/○
Pasture	No	No	No	Yes/+	Yes/○	Yes/○

Table 2. Beef Cattle Numbers for 2023

Country	Baseline	Tax	Difference	Difference in %
Argentina	55,732	56,192	459	0.82%
Australia	31,003	31,830	827	2.67%
Brazil	232,295	240,903	8,608	3.71%
Canada	12,427	13,158	731	5.88%
China	102,812	102,775	(38)	-0.04%
Egypt	6,111	6,319	208	3.40%
EU	59,104	59,127	23	0.04%
Indonesia	13,534	13,877	343	2.54%
India	259,677	258,603	(1,074)	-0.41%
Japan	3,209	3,216	7	0.20%
Korea	2,477	2,518	41	1.64%
Mexico	28,612	28,882	270	0.94%
New Zealand	6,459	6,676	218	3.37%
Philippines	6,387	6,525	138	2.17%
Russia	8,354	8,362	8	0.09%
Thailand	7,150	7,382	232	3.25%
USA	84,235	66,809	(17,427)	-20.69%
Ukraine	1,655	1,654	(0)	-0.02%
Viet Nam	9,352	11,203	1,851	19.79%
World Total	930,585	926,010	(4,575)	-0.49%

Table 3. Emission in Metric Tons of CO_2-Equivalent (Mean 2009-2023)

	Enteric Fermentation (CH_4)		Pasture (N_2O)		Manure (N_2O)		Manure (CH_4)	
	2023	Mean	2023	Mean	2023	Mean	2023	Mean
Baseline								
Argentina	65.5	62.7	21.5	20.6	0.8	0.7	1.2	1.1
Brazil	242.5	224.0	79.7	73.6	2.8	2.6	4.3	4.0
China	101.5	95.6	19.8	18.7	18.2	17.2	2.2	2.0
European Union	70.7	74.8	9.3	9.9	6.7	7.1	8.7	9.2
India	147.2	140.5	7.6	7.3	1.5	1.4	10.9	10.4
Indonesia	13.3	12.1	2.6	2.4	2.4	2.2	0.3	0.3
Mexico	31.9	29.7	10.0	9.3	2.3	2.1	1.2	1.1
United States	93.7	93.9	29.4	29.5	6.7	6.7	2.4	2.4
Total	766.4	733.3	180.1	171.2	41.4	40.0	31.2	30.6
Tax								
Argentina	66.1	62.8	21.7	20.6	0.8	0.7	1.2	1.1
Brazil	251.1	225.7	82.5	74.2	2.9	2.6	4.5	4.0
China	101.4	95.6	19.8	18.7	18.2	17.2	2.2	2.0
European Union	70.8	74.8	9.3	9.9	6.7	7.1	8.7	9.2
India	146.6	140.2	7.6	7.2	1.5	1.4	10.9	10.4
Indonesia	13.7	12.2	2.7	2.4	2.5	2.2	0.3	0.3
Mexico	32.1	29.7	10.1	9.3	2.3	2.1	1.2	1.1
United States	74.4	84.5	23.3	26.5	5.3	6.0	1.9	2.2
Total	756.2	725.4	177.1	168.8	40.1	39.4	30.8	30.3
Difference	(10.3)	(7.9)	(3.0)	(2.4)	(1.2)	(0.7)	(0.4)	(0.2)

Table 4. Difference in Emissions in Metric Tons of CO_2-Equivalent from Land-Use Change and Pasture Expansion

Elasticity	0		0.5		0.75	
	Average	Sum	Average	Sum	Average	Sum
Argentina	0.9	14.2	0.3	4.9	(0.2)	(2.5)
Australia	(3.0)	(48.3)	(1.5)	(24.0)	(0.7)	(11.8)
Brazil	255.1	4,080.9	255.1	4,080.9	255.1	4,080.9
Canada	20.0	320.2	9.2	146.8	4.5	72.0
China	(0.6)	(9.1)	(0.5)	(7.5)	(0.4)	(6.9)
Egypt	9.9	158.8	4.5	71.8	2.1	32.8
European Union	(0.0)	(0.4)	(0.0)	(0.4)	(0.0)	(0.4)
Indonesia	18.8	301.5	5.6	88.9	1.9	30.2
India	(1.6)	(26.0)	(0.9)	(14.6)	(0.6)	(9.1)
Mexico	(0.3)	(4.7)	(0.2)	(3.1)	(0.1)	(1.9)
Morocco	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
Malaysia	(0.0)	(0.7)	(0.0)	(0.7)	(0.0)	(0.7)
Other Africa	(0.2)	(2.5)	(0.2)	(2.5)	(0.2)	(2.5)
Other Asia	1.1	18.4	0.3	4.1	(0.1)	(1.3)
Other Latin America	(0.4)	(6.9)	(0.4)	(6.9)	(0.4)	(6.9)
Philippines	(0.2)	(3.8)	(0.4)	(6.5)	(0.5)	(7.5)
Russia	(0.2)	(3.7)	(0.1)	(2.3)	(0.1)	(1.1)
Thailand	16.2	258.9	(0.3)	(4.4)	(0.1)	(1.9)
USA	(24.1)	(385.7)	(13.3)	(212.5)	(7.3)	(117.6)
Viet Nam	97.0	1,551.3	3.3	53.0	1.4	22.6
World Total	388.3	6,212.6	260.3	4,164.9	254.1	4,066.2

Figure 1: General Model Structure

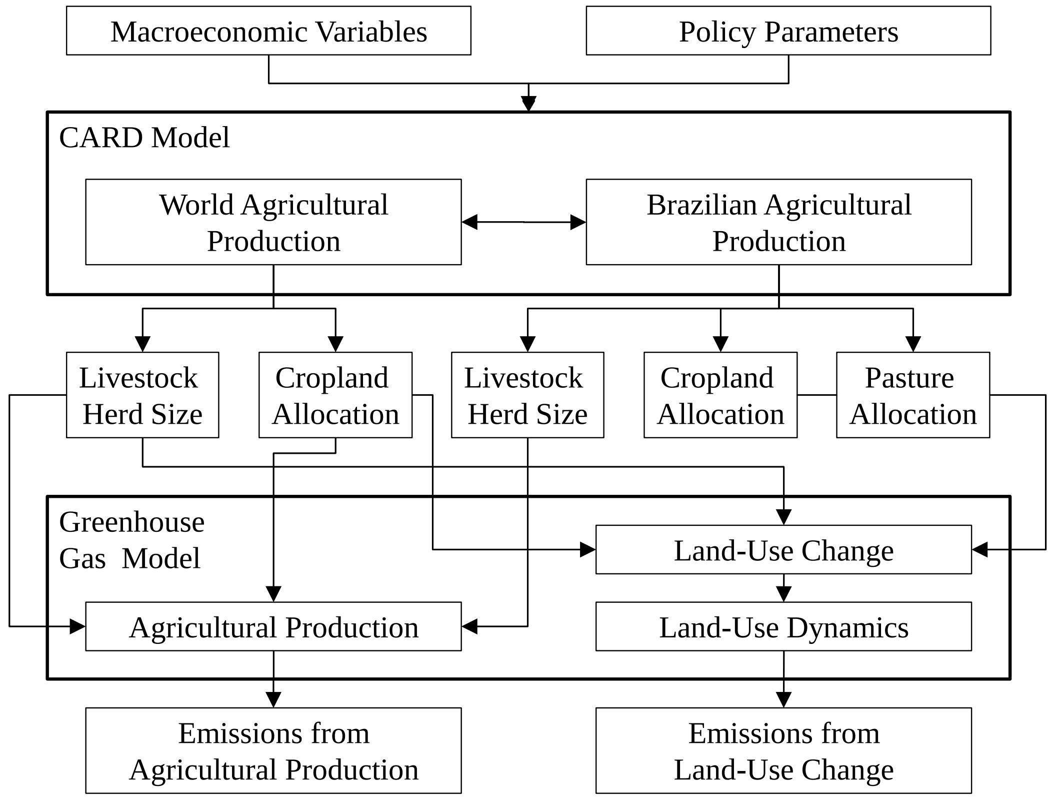

Figure 2: Land-Use Dynamics and Idle Cropland

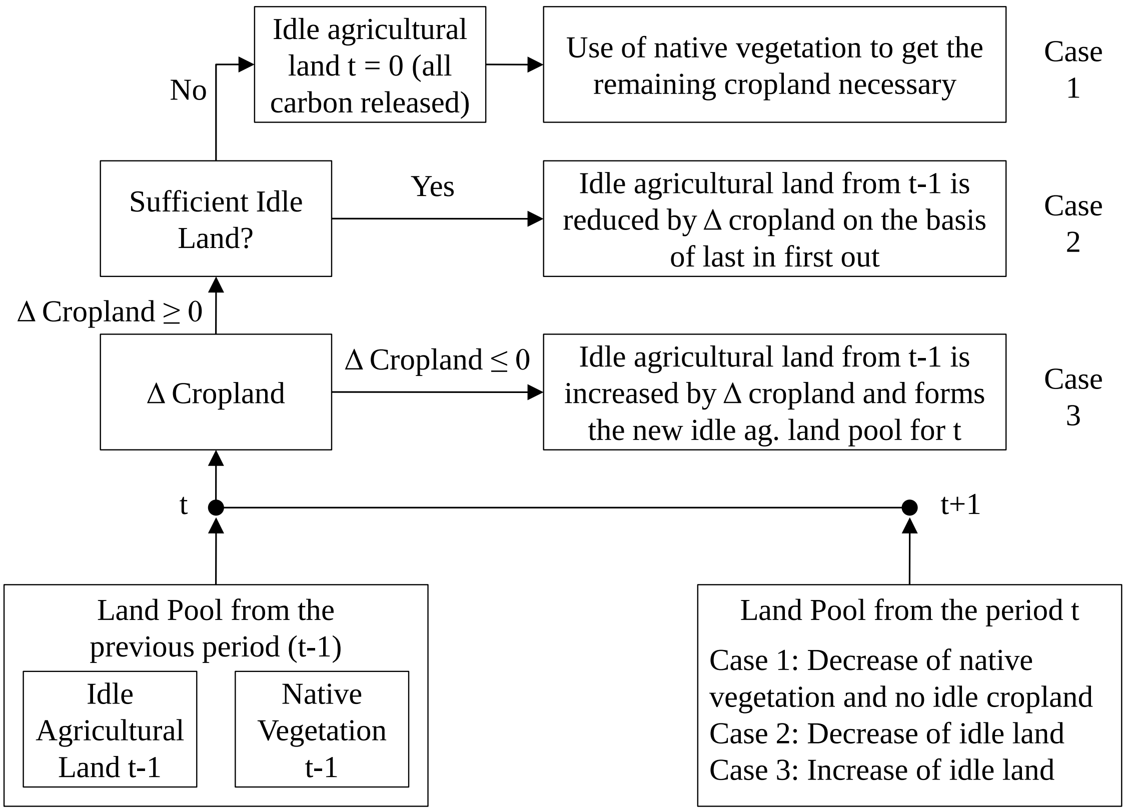

Figure 3: Cattle Herd Size in Brazil and the United Sytates

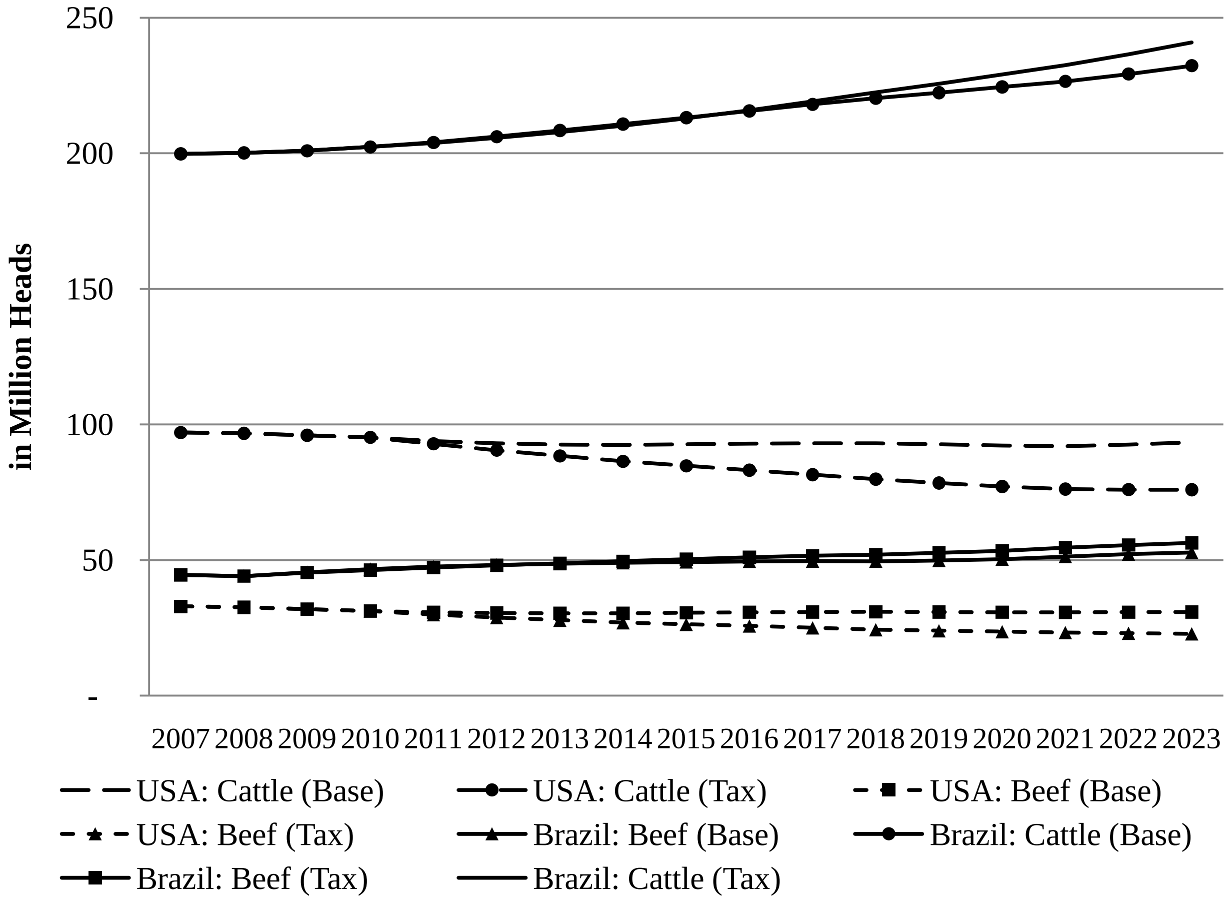

Figure 4: Pasture Area in Selected Regions of Brazil