Appendix 1 – GTAP Modeling

(Appendix to Boucher, D. et al. 2013. *Climate-Friendly Land Use: Paths and Policies toward a Less Wasteful Planet*. Union of Concerned Scientists. Online at: www.ucsusa.org/lesswastefulplanet)

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Methodology

We used a computable general equilibrium model (CGE) developed by the Global Trade Analysis Project (GTAP) at Purdue University to analyze the impact of changing global protein consumption patterns on land use. GTAP has been extensively used for policy analyses such as examining the impacts of tariffs, quotas and subsidies and more recently in land-use analysis. Some advantages of GTAP include transparency, ease in application, modifiability, replication, peer review and consistent improvement. The standard GTAP model is a multi-region, multi-sector model which assumes perfect competition and constant returns to scale of technology. The model is publicly available and documented (Hertel and Tsigas 1997). The GTAP database consists of input-output tables and international trade data which represent the global economy.

The basic structure of the model includes: industrial sectors, households, governments, and global sectors across countries. Each region (e.g. the E.U.) has a representative “regional household” and “firms”. Countries and regions in the world economy are linked together through trade. International trade is linked through Armington substitution in which goods are differentiated by country of origin. The households collect income and spend it on three types of expenditures: private (consumer), government and savings. Firms use primary and intermediate inputs to produce final goods. Firms can either buy inputs from other firms or import intermediate inputs from other regions. They pay wages to households in return for employing land, labor, capital and natural resources. Firms can sell output to other firms, private households, government and investment, and can also export their goods.

There are five main factors of production in GTAP: labour (skilled and unskilled), capital, natural resources and land. The factors land and labor are assumed to be mobile, that is, they can move across sectors and the returns for these factors are identical across the different sectors in the economy. Land and natural resources, on the other hand are "sluggish"; therefore, farmland values can vary across sectors.

The production function in GTAP assumes a constant elasticity of substitution (CES) when firms decide on the percentage of primary factors of production and intermediate inputs to purchase from other firms. We used the CES value of zero, which is standard in GTAP, to determine the degree of substitution between primary production factors and intermediate inputs (Hertel et al 2008). Intermediate inputs are used by firms in GTAP assuming a constant returns to scale production function , and firms choose a mix of primary production factors (including land) using a CES parameter value of 0.24 for crops. Prices and quantities are simultaneously determined in both factor markets and commodity markets (Hertel et al 2008b).

We used version 7 of GTAP database which has 2004 as the base year for the data. This version consists of 113 regions, a combination of individual countries and aggregate regions and 57 sectors. We aggregated the data into 7 regions[1] and 24 sectors, both for easy of computation and in order to focus on specific countries/sectors that were of interest to us. In aggregating the sectors, we follow the same classification as used by Birur, Hertel and Tyner (2008) with the exception of isolating specific sectors and regions that are the focus of our analysis. We selected these regions because changing protein consumption pattern in these regions would have a significant impact on land use. GEMPACK is used to solve the model (Harrison and Pearson, 1996).

Description of Scenarios

A description of the two scenarios we analyzed is given in Table 1 while the GTAP code corresponding to the scenarios is provided in Section A. In order to analyze the impact of changing protein consumption to meet dietary guidelines, we used the following procedure:

- We first identified current consumption of beef, poultry, and pork and other meats using 2004 FAO data

[1] Africa, Australia, China, European Union (EU), India, Latin America (LA), Rest of the world (ROW), South East Asia (SE Asia) and United States (USA)

- We then used the Population Reference Bureau data (2010) for age demographics and USDA values for daily individual protein requirements (average of 51 g/day for an adult and average of 33 g/day for a child under 15 years of age) to determine country's overall daily protein need.

- Next, using a global average, we determined the percentage of protein requirement that would come from meat.

- We then calculated total amount of poultry/pork and beef for the "Beef and Chicken/Poultry" modeling scenario as follows:
  - In countries consuming over 42 g beef/day (Pan et al 2012) it was reduced to that level, and the difference was made up with poultry/pork on a grams of protein basis
  - In the case of the countries under-consuming protein from meat, it was brought up to the Country's requirement using poultry/pork to fill the need

- For the "Beef" scenario, we reduced beef consumption in the same way but did not change poultry/pork consumption.
- We then used USDA values to estimate that beef has 0.4 g protein/g meat, pork has 0.2 g protein/g meat, and chicken has 0.3 g protein/g meat
- Finally, changes in meat consumption were summed for our selected regions

To analyze the impact of increased/decreased protein requirements, we apply hypothetical taxes or subsidies on the private household demand (domestic and imported) in selected food sectors and regions so that final consumption of specific food sectors would conform to the dietary recommendations. Thus, in the case of a tax, the price paid by households for the taxed good is greater than that of the good's market price, and the reverse in the case of a subsidy. Since our focus is on the implications of changing meat consumption patterns, we do not impose taxes or subsidies on the output of other sectors.

To estimate changes in crop and pasture acreage for the U.S. we use the USDA 2012 data (USDA-ERS 2012a, 2012b)[2]. To estimate crop and pasture acreage changes in Australia, Latin America, India and China we use the Ramakutty 2007 database while the 2004 GTAP 7 database (GTAP, 2011) is used for the EU, ROW, Africa and South East Asia[3].

Results

Beef Scenario

Results of the beef scenario for select countries are presented in Table 2. This scenario analyzed the impact of a hypothetical reduction in global beef consumption of private households in select regions. In order to implement this scenario, we shocked GTAP'S "Cattle meat" sector which includes bovine products other than the poultry and pork sectors for the respective regions. According to our calculations, countries that would need to have the largest reduction (shock) in beef consumption to meet the dietary guidelines were USA (64%) followed by Australia (58%), Latin America (41%), EU(24%), Rest of the World (13%) and Africa (1%). We eliminated India and China from our shock since the per capita beef consumption in these countries was within the recommended dietary guidelines. For the US we find that U.S. domestic beef production declines the most, by 40%. This fall corresponds to a decline of 37% in domestic cattle production, which is the intermediate input used for beef production. In Latin America, beef production falls by 24%, in Australia by 22%, EU by 16% and ROW by 10%. The corresponding decline in cattle production is 15 % in Latin America, 10% in Australia and 5% each in the EU and ROW.

In response to the lower demand for beef, the demand for cereal grain, which is the major feed for cattle, also declines. In the US, domestic cereal grain production declines by 7%. This corresponds to a 4% decrease in cereal grain acreage, or about 3.5 million acres. In other countries, the decline in cereal grain production is much smaller (1% or less) due to the production of pasture raised cattle for which cereal grain is not a prominent feedstock. Finally, with the decline in beef production, pasture land declines in most regions. The largest declines

[2] For fruits and vegetable, we use 2011 data (USDA ERS, 2012 a, 2012b)

[3] This is done because the aggregation of countries in the Ramakutty 2007 database for the EU, ROW ,Africa and South east Asia differs from our GTAP aggregation.

are in the US (16%), Latin America (7%) and Australia (5%). This corresponds to a 100 million acreage reduction in pasture land in the US, 82 million acres in Latin America, and 29 million acres in Australia, as well as 2 million acres in the EU. The total of global pasture land declines by 243 million acres, or just under 100 million hectares..

Beef and Chicken/ Poultry Scenario:

Results of the beef and chicken/poultry scenario for selected countries are presented in Table 2. This scenario analyzed the combined effect of a hypothetical reduction in global beef consumption and an increase in poultry/pork consumption of private households in select regions. In order to implement this scenario, we shocked GTAP'S "Cattle meat" sector and also the "Other Meat" sector, which includes poultry and pork products. This was implemented as follows: In countries under-consuming protein from meat it was brought up to the country's requirement using poultry/pork to fill the need. In countries consuming over 42 g beef/day (Pan et al 2012) it was reduced, and the difference was made up with poultry/pork on a grams of protein basis. In implementing the poultry shock we shocked the processed product "chicken" in developed countries and the intermediate product "poultry" in developing countries. This was done as poultry is sold relatively unprocessed in many developing countries. As with the beef scenario, we eliminated China from our shock since its per capita beef consumption was within the recommended dietary guidelines.

With the combined shock of reduced beef and increased chicken consumption, the U.S. domestic beef production declines by 36% and chicken production increases by 36%. This corresponds to a decline of 31% in domestic cattle production and a 19% increase in poultry production, which are the intermediate inputs used for beef and chicken production. In response to the lower demand for beef, cereal grain acreage in the U.S. also declines by little over 5% decrease, or about 4.5 million acres. In Australia beef production falls by 22% while chicken production increases by 37%. In Latin America, beef production falls by 24% while poultry production increases by 7%. As in the beef scenario, there is only a slight decline (less than 1%) in domestic cereal grain production in both Australia and Latin America. In India, poultry production increases by 166%. Incidentally, we shocked domestic demand for poultry in India by

250%[4] to meet protein requirements. In Africa, domestic poultry production increases by 22% while beef production falls by 1%. Finally, with the decline in beef production, pasture land declines in most regions. The largest declines in percentage terms are in India (22%), the US (16%), Latin America (8%) and Australia (3%), EU (2%). Most of the decline in pasture land in India is a result of decline in milk production, as consumers' demand for milk declines with the increase in protein consumption from chicken.

In absolute terms, these results correspond to a 95 million acreage reduction in pasture land in the US, 98 million acres in Latin America, 20 million acres in Australia, 25 million acres in Africa, 11 million acres in the EU and 6 million acres in India.

[4] The actual percentage increase need to meet protein requirements as per dietary guideliness is much larger in India (over 500%). We reduced this shock for easy of computation as there was no model solution with the large shock.

Table1. Food Consumption Scenarios

Scenario	"Beef" Scenario 1	"Beef and Poultry/Chicken" Scenario 2
Africa	-0.58%	52.17%
Australia	-58.58%	63.5%
European Union	-23.66%	10.3%
China	0.00%	0.00%
India	0.00%	250%
Latin America	41.33%	48.11%
Rest of World	12.71%	20.15%
South East Asia	0%	13.11%
United States	64.08%	53.32%

Table 2- Results of the Scenarios

a) Results of the Beef Scenario in Selected Countries

	USA	Latin America	Australia	European Union
% Change in Production of Final Product				
Beef	-40%	-24%	-22%	-16%
% Change in U.S. Production of Intermediate Product				
Cattle	-36%	-15%	-10%	-5%
Crop/Pasture Production Changes				
% Change in Cereal Grain Acreage	-5%	0.6%	1.1%	0.05%
Initial Cereal Grain Acreage (million acres)	104.8	78.9	125	72.6
Change in Cereal Grain Acreage (million acres)	-4.2	0.46	0.19	0.036
% Change in Pasture Acreage	-16%	-6.8%	-4.7%	-1.2%
Initial Pasture Acreage (million acres)	614	1207.2	621.9	138.6
Change in Pasture Acreage (million acres)	-100.1	-82.0	-29.3	-1.7

2b) Results of the Poultry/ Chicken Scenario in Selected Countries

	USA	Latin America	Australia	European Union	India	Africa
% Change in Production of Final Product						
Beef	-36%	-24%	-22%	-16%	-3%	-1%
Chicken/Poultry	36%	7%	37%	7%	166%	21%
Crop/Pasture Production Changes						
% Change in Cereal Grain Acreage	-5%	-0.3%	-1%	0.1%	-17%	-1.5%
Initial Cereal Grain Acreage (million acres)	104.8	78.9	125	72.6	72.4	125.0
Change in Cereal Grain Acreage (million acres)	-4.5	-0.27	-0.23	-0.18	-12.0	-1.9
% Change in Pasture Acreage	-15%	-8%	-3%	-2%	-22%	-2.3%
Initial Pasture Acreage (million acres)	614	1207.2	621.9	138.6	26.3	1090.1
Change in Pasture Acreage (million acres)	-94.7	-97.6	-19.8	-2.7	-5.9	25.3

Section A – GTAP Code

A simulation in GTAP involves a set of commands in conjunction with a given database, equations, and parameters that direct the model to calculate a new equilibrium. Variables in GTAP are either endogenous or exogenous. Endogenous variables are determined within the model. Household demand is an example of an endogenous variable. Exogenous variables are inputs into the model. Examples of exogenous variables in GTAP include population, tax rates, and tariff rates.

Beef Scenario

The objective of this scenario is to examine the impact of a decrease in the private household demand for beef in selected regions, assuming no other changes in exogenous variables. Total beef demand is comprised of both domestic and imported demand. To calculate the impacts of such an increase in demand, we reduce (or in GTAP terms “shock”) both the domestic demand and import demand for beef by a certain percentage based on the specific region and the extent to which the region needs to reduce per capita beef consumption to in order to meet dietary guidelines. However, household demand is an endogenous variable and cannot be directly shocked. Therefore, we shock another variable which could impact the beef demand. Since a tax on beef consumption could reduce consumer demand, we find this to be an appropriate variable to determine the amount of tax. This is accomplished in GTAP through the following commands:

```
swap qpd("beef","USA") = tpd("beef","USA");

swap qpm("beef","USA") = tpm("beef","USA");

swap qpd("beef","Australia") = tpd("beef","Australia");

swap qpm("beef","Australia") = tpm("beef","Australia");

swap qpm("beef","EU") = tpm("beef","EU");

swap qpd("beef","EU") = tpd("beef","EU");
```

```
swap qpm("beef","LatinAmerica") = tpm("beef","LatinAmerica");

swap qpd("beef","LatinAmerica") = tpd("beef","LatinAmerica");

swap qpm("beef","RestofWorld") = tpm("beef","RestofWorld");

swap qpd("beef","RestofWorld") = tpd("beef","RestofWorld");

swap qpm("beef","Africa") = tpm("beef","Africa");

swap qpd("beef","Africa") = tpd("beef","Africa");

Shock qpd("Beef","USA") = -64.08;

Shock qpm("Beef","USA") = -64.08;

Shock qpd("Beef","Australia") = -58.68;

Shock qpm("Beef","Australia") = -58.68;

Shock qpd("Beef","Africa") = -0.58;

Shock qpm("Beef","Africa") =  -0.58;

Shock qpd("Beef","EU") = -23.66;

Shock qpm("Beef","EU") =  -23.66;

Shock qpd("Beef","LatinAmerica") = -41.33;
```

In the first command, *qpd* and *tpd* represent the percentage change in the domestic private household demand for beef and the tax rate on private household consumption of domestically produced beef, respectively. In the second command, *qpm* and *tpm r*epresent the percentage changes in the private household demand for beef imports and the tax rate on private consumption of imported beef, respectively. The first two commands endogenize the tax rate on domestic and imported beef respectively in the select regions and exogenize the domestic and import demand for beef in these regions. That is, the variables *tpm* and *tpd* are now endogenous while *qpd* and *qpm* are exogenous and can therefore be shocked directly. The “shock qpd” and “shock qpm” commands shock the domestic and imported demand for beef respectively in the respective regions. The model uses a simulation process by starting with an initial equilibrium and a given system of equations and increasing the tax until the domestic and imported demand decrease by the specified percentage for the different regions. It then solves for a new equilibrium.

Beef and Chicken/Poultry Scenario

In order to implement this scenario, we shocked GTAP'S "Cattle meat" sector and "Other Meat" sector which includes poultry and pork products. In this scenario we analyzed the combined effect of reducing beef consumption in countries that are over-consuming, replacing the reduction in beef consumption with poultry/pork protein and increasing poultry /pork consumption in countries that are under-consuming protein. In implementing the poultry shock we shock the processed product "chicken" in developed countries and the intermediate product "poultry" in developing countries. This was done as poultry is sold unprocessed in developing countries. Reduction in beef consumption was done as specified in the Beef scenario. To increase poultry/pork consumption , we exogenize domestic and imported demand for protein and dairy for select regions:

```
swap qpm("poultry","Africa") = tpm("poultry","Africa");

swap qpd("poultry","Africa") = tpd("poultry","Africa");

swap qpm("chicken","Australia") = tpm("chicken","Australia");

swap qpd("chicken","Australia") = tpd("chicken","Australia");

swap qpm("chicken","EU") = tpm("chicken","EU");

swap qpd("chicken","EU") = tpd("chicken","EU");

swap qpm("poultry","LatinAmerica") = tpm("poultry","LatinAmerica");

swap qpd("poultry","LatinAmerica") = tpd("poultry","LatinAmerica");

swap qpm("poultry","SEAsia") = tpm("poultry","SEAsia");

swap qpd("poultry","SEAsia") = tpd("poultry","SEAsia");
```

swap qpm("poultry","RestofWorld") = tpm("poultry","RestofWorld");

swap qpd("poultry","RestofWorld") = tpd("poultry","RestofWorld");

swap qpm("chicken","USA") = tpm("chicken","USA");

swap qpd("chicken","USA") = tpd("chicken","USA");

We shock the qpd and qpm to analyze the impacts.

To increase the domestic and imported demand for chicken/poultry in select regions:

Shock qpd("poultry","LatinAmerica") = 48.11;

Shock qpm("poultry","LatinAmerica") = 48.11;

Shock qpd("poultry","SEAsia") = 13.11;

Shock qpm("poultry","SEAsia") = 13.11;

Shock qpd("chicken","EU") = 10.30;

Shock qpm("chicken","EU") = 10.30;

Shock qpd("poultry","RestofWorld") = 20.15;

Shock qpm("poultry","RestofWorld") = 20.15;

Shock qpd("poultry","India") = 250;

Shock qpm("poultry","India") = 250;

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