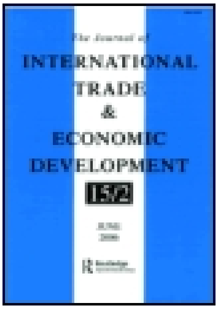

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A gravity model to account for vertical linkages between markets with an application to the cattle/beef sector

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A gravity model to account for vertical linkages between markets with an application to the cattle/beef sector

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A gravity model is developed to explain bilateral trade flows in primary and processed commodities within the same agri-food supply chain. It accounts for vertical production linkages, trade and domestic policies, and supply rigidities at the farm level. Our application focuses on cattle/beef trade flows between 42 countries. The estimated parameters of the model are used to simulate trade flows. We found large differences in the impacts of the full and partial liberalization scenarios. A parametric bootstrap procedure is used to generate confidence intervals around predicted trade liberalization outcomes.

Keywords: gravity model; tariffs; trade barriers; trade liberalization

JEL Classifications: F13, Q17

1. Introduction

Taking a long view of trade liberalization, it is apparent that the global trading system is in a critical transition period. Between the Great Depression and World War II, industrial tariffs averaged about 40% or roughly 10 times the current average (OECD 2003). However, Gibson et al. (2001) estimated that the average tariff on agricultural products at the end of the Uruguay Round (UR) implementation period was about 60%. In some sense, the work initiated in the 1940s to lower tariffs on industrial goods is nearly complete. Most of the lessons that were learned from liberalizing trade in industrial products still apply even though agri-food market characteristics add a whole new set of modeling issues. For instance, supply rigidities due to sanitary regulations or non-tariff barriers can emerge at various degrees in agri-food supply chains. Comprehensive liberalization

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plans must recognize the vertical linkages between the upstream and downstream industries as farm policies impact on the competitiveness of primary producers and processors alike.

The objective of the article is to develop an empirical procedure that explains bilateral trade flows of a processed agri-food commodity and a primary agricultural product. Given the success of gravity models at explaining trade determinants (Anderson and van Wincoop 2003), we propose a gravity framework that accounts for vertical linkages in an agri-food supply chain. Our model yields empirically tractable bilateral trade flow equations which are then used to simulate the impacts of trade liberalization in the cattle/beef markets. We chose this specific application for a number of reasons. First, cross-hauling in cattle and beef is common and thus these markets provide an interesting case-study. Second, trade liberalization effects in these two markets are difficult to predict because countries often have opposite net trade positions in cattle and beef such as Argentina and the United States (US). Third, tariffs, and domestic and export subsidies vary a lot from one country to another. The European Union's (EU's) tariff and export subsidy rates on beef are both in excess of 50% while some countries follow a laissez-faire policy such as Australia. Because several instruments are used to support cattle and beef products, several trade liberalization scenarios can be entertained.

The modeling approach showcases two important structural parameters: the elasticity of substitution for beef and the elasticity of transformation for live cattle. The former elasticity measures the consumers' willingness to substitute beef from different origins while the latter captures the ease with which a live cattle exporter can substitute one destination for another. Our elasticity of substitution estimate is low and supports the hypothesis that there is significant product differentiation with respect to the origin of beef at the wholesale and possibly consumer levels as the importers' demand ought to reflect consumer preferences.

Explicit transaction costs such as tariffs and transportation costs are directly accounted for in the model. Non-tariff barriers in agri-food supply chains are notoriously disruptive (Beghin and Bureau 2001) and may introduce supply rigidities at the farm level. Hence, an elasticity of transformation captures transaction costs associated with the presence of significant impediments in substituting cattle exports across markets from the exporters' perspective. The empirical model yields an estimate of the elasticity of transformation which is quite low, and thus consistent with the presence of significant non-tariff measures.

Econometric studies pertaining to the liberalization of the cattle/beef sector are usually limited to a narrowly defined geographic area. For example, Wachenheim, Mattson, and Koo's (2004) analysis applies to North American beef and cattle trade while Kim, Kim, and Veeman's (2004) study pertains to the South Korean beef market. In contrast, gravity models for agricultural products are typically estimated on datasets involving a large number of countries (e.g. Koo, Kennedy, and Skripnitchenko 2006; Sarker and Jayasinghe 2007). The applications of the gravity equation for agricultural products are conducted on broad aggregates (e.g. Furtan and van Melle 2004; Paiva 2005; Koo, Kennedy, and Skripnitchenko 2006) or at the commodity level (e.g. Sarker and Jayasinghe 2007; Susanto, Rosson, and Adcock 2007). However, the gravity equations used in these studies have not accounted for the vertical linkages between primary agricultural commodities and processed food products. The main contribution of this article is to provide a framework that explicitly accounts for the impacts of policies in the upstream level on trade flows in the downstream sector (and vice versa). The empirical procedure in this article focuses on two markets that are vertically related and proposes bootstrap methods to test hypotheses about changes in trade positions induced by trade liberalization.

The main issue in the empirical specification of the model is the endogeneity of cattle prices. Due to the vertical linkages between the cattle and beef markets and the assumption about market structure, beef prices in the model can be expressed as a function of cattle prices and other input costs using a constant mark-up rule. Cattle prices are determined by market clearing conditions involving bilateral cattle export supply functions and beef import demand schedules. At the estimation stage, the potential simultaneity bias between cattle prices and trade flows is tackled with a Poisson generalized method of moments (GMM) estimation procedure. The empirical model in this article accounts for zero bilateral trade flows that are prevalent in commodity level datasets and for the type of heteroskedasticity commonly characterizing gravity trade models. The parameters' estimates are used to simulate the impacts of tariff and subsidy reductions on trade flows of cattle and beef.

Our results confirm that beef is a differentiated product and that non-tariff barriers and other supply rigidities are significant impediments to cattle trade. We found that trade liberalization would have opposite effects on world trade in cattle and beef. World trade in cattle would fall whereas world trade in beef would increase. Several factors contribute to this pro-processing liberalization outcome such as tariff escalation, reductions in domestic support toward beef production, and the aforementioned non-tariff barriers impeding cattle trade. We found large differences in the effects of full and partial liberalization scenarios not only at the aggregate level but also at the country level.

The remainder of the article is structured as follows. The next section presents the theoretical foundations of our gravity model. It highlights the vertical linkages between the cattle and beef sectors. The third section describes the data and the econometric procedure used to estimate the parameters of the model. The fourth section presents results from two liberalization scenarios and discusses their policy implications. The final section reviews the main results.

2. The theoretical model

Consider a two-tier consumer utility representation. The upper tier is a Cobb-Douglas function that determines the share of income spent on processed goods. The lower tier is a Dixit and Stiglitz's (1977) constant elasticity of substitution (CES) function over varieties of a given good. We consider a world with Z ($z = 1, \ldots, i, j, \ldots, Z$) countries and a representative sector producing the processed good f (where f stands for food). We assume that each variety of f is produced by one firm and that there are a total of n_z^f producers of f in country z. The lower-tier utility function associated with the consumption of good f for a representative consumer in country i is:

$$U_i^f = \left(\sum_{z=1}^{Z} \sum_{v=1}^{n_z^f} q_{iz}^f(v)^{1/\tilde{\sigma}} \right)^{\mu\tilde{\sigma}} \tag{1}$$

where μ is the constant share of income spent on the processed good f, $\tilde{\sigma} \equiv \sigma/(\sigma - 1)$with σ representing the elasticity of substitution between varieties of good f, $q_{iz}^f(v)$measures consumption of variety v of f produced by a firm in country z.

Weak separability implies that the representative consumer maximizes the lower-tier utility function subject to the budget constraint, $\mu Y_i = \sum_{z=1}^{Z} \sum_{v=1}^{n_z^f} p_z^f \tau_{iz}^f s_{iz}^f q_{iz}^f(v)$, where Y_i represents total income of the representative consumer in country i, p_z^f is the seller's given price for good f produced in country z,$\tau_{iz}^f \geq 1$ is the *ad valorem* equivalent trade cost associated with shipping goods from country z to country i, and $s_{iz}^f \leq 1$ measures export subsidies offered by country z (i.e. it is invariant across export markets and equals one when $z = i$). Country i's total import demand function of good f purchased from country j is:

$$Q_{ij}^f = n_j^f q_{ij}^f = \mu Y_i \frac{(p_j^f \tau_{ij}^f s_{ij}^f)^{-\sigma} n_j^f}{\Sigma_z (p_z^f \tau_{iz}^f s_{iz}^f)^{1-\sigma} n_z^f} \tag{2}$$

Let $\bar{Q}_j^f$ represent total output of good f in country j. For future reference, define the following identity which expresses trade flows as a fraction of total output (i.e. total exports including *intranational* trade flows) in the processing sector:

$$Q_{ij}^f = \frac{Q_{ij}^f}{\sum_z Q_{zj}^f} \overline{Q}_j^f \tag{3}$$

The key assumption in the consumers' utility maximization problem is that processed goods are differentiated. In contrast, we assume that primary commodities are not differentiated on the basis of their intrinsic qualities.

Commodities are often blended and priced based on a benchmark quality. According to Rauch (1999) and Feenstra (2004, 166), this can only be done when differentiation is limited. It would be possible in theory to allow differentiation at the farm level and preserve the identity of the final product according to the origin of the primary product. However, data limitations and concerns over tractability make the homogeneity assumption most convenient for empirical purposes.

We posit that destinations are not perfectly substitutable for exporters of primary agricultural commodities. This conjecture is consistent with the presence of supply rigidities at the farm level due to sanitary regulations, non-tariff barriers and other impediments to agricultural trade.[1] Imperfect substitutability across destinations for exports of primary commodities is modeled through a constant elasticity of transformation. This concept was first introduced by Powell and Gruen (1968) and later used by Bergstrand (1985, 1989) and Baier and Bergstrand (2001).[2] It is assumed that the production process of a given commodity a (where a stands for primary agricultural commodity) can be decomposed into two different stages. First, each firm produces an aggregate output (denoted $\breve{q}_j^a$) which is subsequently tailored to each particular market according to the constant elasticity of transformation (CET) function:

$$\breve{q}_j^a = \left(\sum_z \left(q_{zj}^a \right)^{1/\tilde{\gamma}} \right)^{\tilde{\gamma}} \tag{4}$$

where $\tilde{\gamma} \equiv \gamma/(1+\gamma)$ with γ representing the elasticity of transformation that takes a minimum value of zero if products are not substitutable and a value of infinity for the case of perfect substitutability across destination countries, and q_{zj}^a is the production by country j destined to country z. Hence, cattle producers must incur a cost to tailor their product to a particular market. However, there will be a unique free-on-board (fob) cattle price in each market because buyers consider cattle as a homogenous good.

The technology used to produce the primary commodity is homothetic and is summarized by the cost function$(c_j^a)^\alpha (\breve{q}_j^a)^\beta$, where c_j^a is a cost indicator specific to country j and commodity a and $\alpha,\beta > 0$. The bilateral export supply functions of a representative producer in country j are determined by maximizing the profit function:

$$\pi_j^a = \sum_z p_z^a \tau_{zj}^a s_{zj}^a \theta_j^a q_{zj}^a - (c_j^a)^\alpha (\breve{q}_j^a)^\beta \tag{5}$$

where p_z^a is the given price of the primary commodity used by firms producing the processed good f in country $z, \tau_{zj}^a \leq 1$ measures trade costs, $s_{zj}^a \geq 1$ measures export subsidies offered by country j, and $\theta_j^a \geq 1$ represents domestic support offered by country *j*. Profit maximizing conditions yield the bilateral export supply function:

$$q_{ij}^{a} = \tilde{\beta}(c_j^a)^{-\tilde{\alpha}} \frac{(p_i^a \tau_{ij}^a s_{ij}^a \theta_j^a)^{\gamma}}{\left[\sum_z (p_z^a \tau_{zj}^a s_{zj}^a \theta_j^a)^{1+\gamma}\right]^{\xi}} \tag{6}$$

where $\tilde{\beta} \equiv (\beta)^{-1/(\beta-1)}$, $\tilde{\alpha} \equiv \alpha/(\beta-1)$, and $\xi \equiv [\gamma - 1/(\beta-1)]/(1+\gamma)$ with $\gamma > 1/(\beta-1) > 0$ for the second-order conditions to be respected. Denote the number of identical producers of the primary agricultural commodity *a* in *j* by n_j^a. Aggregate exports from *j* to *i* are:

$$Q_{ij}^{a} = n_j^a \tilde{\beta}(c_j^a)^{-\tilde{\alpha}} \frac{(p_i^a \tau_{ij}^a s_{ij}^a \theta_j^a)^{\gamma}}{\left[\sum_z (p_z^a \tau_{zj}^a s_{zj}^a \theta_j^a)^{1+\gamma}\right]^{\xi}} \tag{7}$$

For future reference, define the following identity which expresses trade flows as a fraction of total demand of the primary commodity *a* (i.e. total imports including *intranational* trade flows):

$$Q_{ij}^{a} = \frac{Q_{ij}^{a}}{\sum_z Q_{iz}^{a}} \bar{D}_i^a \tag{8}$$

where $\bar{D}_i^a$ is the total demand of the primary commodity *a* in country *i*.

Vertical technological linkages between the primary commodity and the processing good constrain price linkages. Under the assumption of monopolistic competition in the production of consumer-ready goods and constant average variable costs, profit maximization implies a constant mark-up pricing rule in the processing sector:

$$p_j^f / \theta_j^f = \tilde{\sigma}(p_j^a)^{\lambda p} w_j^{\lambda w} r_j^{\lambda r} \tag{9}$$

where $\theta_j^f \leq 1$ represents domestic support offered by country *j*, w_j, and r_j are the wage rate and the price of capital in country *j* (exogenous to the sector producing *f*), respectively, and λ_p, λ_w, and λ_r are the cost parameters associated with their corresponding production factors such that $\lambda_p + \lambda_w + \lambda_r = 1$. A world trade equilibrium condition implies that total sales of processed good *f* are related to total production of primary commodity *a* such that:

$$\sum_z Q_{zj}^{f} = (\phi_j^{af})^{-1} \sum_z Q_{jz}^{a} \tag{10}$$

where $\phi_j^{af} = \lambda_p (p_j^a)^{\lambda_p - 1} w_j^{\lambda_w} r_j^{\lambda_r}$ is the conversion factor between the primary commodity and the processed good. Equation (10) is used to solve for the equilibrium price of the primary commodity in each country after substituting the pricing rule in equation (9) into the import demand function defined in equation (2) and using the export supply function in equation (7):

$$\eta_j^{af}(\cdot) \equiv p_j^a = \left[\phi_j^{af} \frac{\sum_z \mu Y_z (\tilde{\sigma} w_j^{\lambda w} r_j^{\lambda r})^{-\sigma} \dfrac{(\tau_{zj}^f s_{zj}^f \theta_j^f)^{-\sigma} n_j^f}{\sum_{z'} (\tilde{\sigma} (p_{z'}^a)^{\lambda_p} w_{z'}^{\lambda_w} r_{z'}^{\lambda_r} \tau_{zz'}^f s_{zz'}^f \theta_{z'}^f)^{1-\sigma} n_{z'}^f}}{\sum_z n_z^a \tilde{\beta} (c_z^a)^{-\tilde{\alpha}} \dfrac{(\tau_{jz}^a s_{jz}^a \theta_z^a)^{\gamma}}{[\Sigma_{z'} (p_{z'}^a \tau_{z'z}^a s_{z'z}^a \theta_z^a)^{1+\gamma}]^{\xi}}} \right]^{1/(\lambda_p \sigma + \gamma)} \quad \forall j \tag{11}$$

The theoretical model describes the structure of a gravity model for primary and processed products that accounts for vertical linkages, supply rigidities, product differentiation, and policy variables. Naturally, the model lends itself to comparative statics, econometric estimation, and policy simulations. Our focus in the next sections is on the latter two endeavors. Our main purpose is to generate point estimates and confidence intervals to characterize trade liberalization outcomes. Our application focuses on the cattle/beef sector because several countries have different net trade positions for these products and because of significant differences in the level and type of protection used from one country to another. As in Eaton and Kortum (2002), we rely on cross-section data to illustrate the empirical potential of our framework. Given that a cross-section provides a picture of a phenomenon at one point in time, caution should be exercised in the interpretation of the results.[3]

3. Data and estimation strategy

The occurrence of zero trade flows in a dataset grows exponentially with the level of disaggregation in the data. In our dataset, zero trade flows occur in 64% and 42% of the total country pairs in the cattle and beef sectors, respectively. Different approaches have been used to deal with this issue, including replacing the zeros with arbitrary positive values, discarding observations with zeros, or using an estimator robust to the presence of zeros. Santos Silva and Tenreyro (2006) advocated estimating the gravity model in its multiplicative form with a Poisson pseudo-maximum likelihood (PPML) estimator because this estimator performs well given the patterns of heteroskedasticity likely present in trade flow data.[4] The multiplicative form gets around the issue of arbitrarily modifying the dependent variable when using a log-linearized form of the gravity equation. Therefore, we estimate the multiplicative form of the gravity equations in equations (3) and (8) as:

$$Q_{ij}^{f} = \exp\begin{pmatrix} \ln Y_i + \ln \bar{Q}_j^f - \sigma \ln(\tilde{\sigma} w_j^{\lambda_w} r_j^{\lambda_r}) - \sigma \ln(\tau_{ij}^f s_{ij}^f \theta_j^f) \\ +(\sigma - 1)\ln \delta_i^f(\cdot) + \sigma \ln \rho_j^f(\cdot) - \sigma \ln \eta_j^{af}(\cdot) + \kappa^f \end{pmatrix} + e_{ij}^f \tag{12}$$

$$Q_{ij}^{a} = \exp\begin{pmatrix} \ln \bar{D}_i^a + \ln n_j^a - \tilde{\alpha} \ln c_j^a + \gamma \ln(\tau_{ij}^a s_{ij}^a \theta_j^a) \\ -\tilde{\xi} \ln \delta_j^a(\cdot) - \gamma \ln \rho_i^a(\cdot) + \gamma \ln \eta_i^{af}(\cdot) + \kappa^a \end{pmatrix} + e_{ij}^a \tag{13}$$

where $\delta_i^f(\cdot) \equiv [\sum_z (\tilde{\sigma}(p_z^a)^{\lambda_p} w_z^{\lambda_w} r_z^{\lambda_r} \tau_{iz}^f s_{iz}^f \theta_z^f)^{1-\sigma} n_z^f]^{1/(1-\sigma)}$, $\delta_j^a(\cdot) \equiv [\sum_z (p_z^a \tau_{zj}^a s_{zj}^a \theta_j^a)^{1+\gamma}]^{1/(1+\gamma)}$, $\rho_j^f(\cdot) \equiv \left[\sum_z \frac{Y_z(\tilde{\sigma}(p_j^a)^{\lambda_p} w_j^{\lambda_w} r_j^{\lambda_r} \tau_{zj}^f s_{zj}^f \theta_i^f)^{-\sigma}}{\sum_{z'} (\tilde{\sigma}(p_{z'}^a)^{\lambda_p} w_{z'}^{\lambda_w} r_{z'}^{\lambda_r} \tau_{zz'}^f s_{zz'}^f \theta_{z'}^f)^{1-\sigma} n_{z'}^f}\right]^{-1/\sigma}$, $\rho_i^a(\cdot) \equiv \left[\sum_z \frac{n_z^a (c_z^a)^{-\tilde{\alpha}} (p_i^a \tau_{iz}^a s_{iz}^a \theta_z^a)^{\gamma}}{\left[\sum_{z'} (p_{z'}^a \tau_{zz'}^a s_{zz'}^a \theta_z^a)^{1+\gamma}\right]^{\xi}}\right]^{1/\gamma}$, κ^f and κ^a are the constant terms,[5] $\eta_j^{af}(\cdot)$ is specified in equation (11), $\tilde{\xi} \equiv \xi(1+\gamma)$, and e_{ij}^f and e_{ij}^a are stochastic error terms. It is important to note that $\bar{D}_i^a$ is proxied by $\phi_i^{af} \bar{Q}_i^f$ in equation (13) using the technological relationship between primary and processed goods. Also, Y_i is represented by the gross domestic product (GDP), and n_j^a and n_j^f are proxied by the production size of cattle and beef sectors, respectively.

It is common in the gravity literature to separate the international trade costs into policy and other non-policy costs. A multiplicative trade barrier function is assumed such that it can be decomposed into an *ad valorem* tariff and distance function (Anderson and van Wincoop 2003, 2004). The trade barrier specifications for the beef and cattle sectors are:

$$\tau_{ij}^f = t_{ij}^f \, \text{dist}_{ij}^{\psi}; \quad \tau_{ij}^a = t_{ij}^a \, \text{dist}_{ij}^{\chi} \tag{14}$$

where t_{ij}^f and t_{ij}^a are the applied *ad valorem* tariff rates on beef and cattle, dist_{ij} is the distance between countries i and j, and ψ and χ are the trade barriers distance parameters for beef and cattle. The measure of support is represented by the *ad valorem* equivalent rates of domestic support and export subsidies, as specified in the theoretical model.

Transport cost proxies are important variables in gravity models. Previous studies have found that trade elasticities with respect to transport cost and other transaction cost variables are sensitive to the method used to proxy transport cost (Wei 1996; Helliwell 1998; Head and Mayer 2000, 2002). A conventional measure is the greater circle distance between two economic major cities, initially introduced by Wei (1996). Some authors designed more intricate measures that take into consideration the dispersion of economic activity within a region. Head and Mayer (2000, 2002) proposed the following indicator: $\text{dist}_{ij} = \sum_{g \in i} (\sum_{h \in j} \varpi_h \text{dist}_{gh}) \varpi_g$, where dist_{gh} is the distance between the two sub-regions $g \in i$ and $h \in j$, and ϖ_g and

ϖ_h represent the economic activity share of the corresponding sub-region. The *Centre d'Études Prospectives et d'Informations Internationales* (CEPII) used the above formula to create a dataset, but reports bilateral distances for EU countries individually. We applied the Head and Mayer's (2000, 2002) formula to construct a set of bilateral distance indicators between the EU as a whole and non-EU countries. We also used the same formula to compute the transport cost proxy within the EU. The indicators involving non-EU countries are the CEPII estimates.

Bilateral trade volumes of cattle and beef were obtained from the database of the Agricultural Trade Policy Simulation Model (ATPSM) (Peters and Vanzetti 2004).[6] These trade volumes are reported as averages of the 1999–2001 annual trade statistics of the United Nations Conference on Trade and Development (UNCTAD) trade deflator dataset. Trade policies are also taken from the ATPSM dataset. We rely on two separate trade policy variables: (1) applied tariffs found in the Agricultural Market Access Database (AMAD) administered by the Organization for Economic Co-operation and Development (OECD), and (2) exports subsidies as reported by the WTO's member countries in their notifications to the WTO.

Using the Trade Analysis and Information System (TRAINS) dataset, adjustments were made to applied tariffs to account for preferential trade agreements. The applied Most-Favored Nation (MFN) tariff rates are replaced by the applied rates arising from regional and bilateral preferential trade agreements. Table 1 presents summary statistics of the variables. The final set of applied tariffs on cattle imports has a mean of 7% with a standard deviation of 15%. The applied MFN tariff rate of the EU is the highest at 74%. The final set of applied tariffs on beef imports has a mean of 35% with a standard deviation of 58%. The applied MFN tariff rate of the EU is quite high (138%) while that of the US is considerably lower at a rate of 11%. Export subsidies only apply to beef exports and are reported in *ad valorem* equivalent rates. The average rate of export subsidies is 4% with a standard deviation of 19%. Norway and the EU have the highest export subsidy rates at 113% and 54%, respectively. There is also a lot of variability in the bilateral trade flows of cattle and beef. Across all non-zero trade flows, the average cattle trade flow is 2811 Metric Tonnes (MT) of live weight (with a standard deviation of 29,645 MT of live weight) while the average beef trade flow is 3191 MT (with a standard deviation of 28,134 MT).

Our domestic support estimates were taken from the ATPSM database which relied on a UNCTAD compilation of various measures of domestic support that corrects for double counting when domestic and border policies are combined into one instrument (as in the case of an administered price for example). The estimates of domestic support are reported in *ad valorem* equivalent rates in the ATPSM dataset and are based on either the 2000 or 2001 data depending on the country. The set of domestic support measures has a mean of 6% with a standard deviation of 25%. EU and Japan have the

Table 1. Summary statistics of the variables in the model.

Variable	Mean	Standard deviation	Minimum	Maximum
Bilateral trade (cattle, MT of live weight)	2,810.8	29,644.9	0.0	613,886.9
Bilateral trade (beef, MT)	3,191.1	28,134.1	0.0	397,409.8
Tariffs (cattle, % *ad valorem*)	7.2	14.5	0.0	73.8
Tariffs (beef, % *ad valorem*)	34.8	58.1	0.0	345
Export subsidy (beef, % *ad valorem*)	4.0	18.9	0.0	113.2
Domestic subsidy (beef, % *ad valorem*)	5.6	25.3	0.0	130.0
Bilateral distance (KM)	9,503.3	4,938.1	202.1	19,564.0
GDP (million of US $)	659,960.3	1,993,392.9	5,949.7	9,737,783.3
GDPC (US $)	6,822.5	9,916.8	102.4	36,770.4
Production (cattle, thousand head)	25,554.1	54,633.2	393.3	311,104.4
Production (beef, thousand MT)	1,074.4	2,331.4	17.7	12,298.1
Price (cattle, US $ per MT of live weight)	1,251.9	1,145.7	160.9	5,330.7

Notes: The mean and standard deviation for live cattle and beef trade flows are computed based on strictly positive trade flows.

highest estimated rates of domestic support with 130% and 106%, respectively.

Cattle prices and total production in 2000 were borrowed from FAO's Agricultural Producer Price series and FAO's Statistical Yearbook, respectively. Production volumes of beef were collected from the FAOSTAT database. Estimates of GDP were taken from the International Monetary Fund's (IMF) World Economic Outlook Database. Wages are proxied by those in the manufacturing sector and were collected from the United Nations Industrial Development Organization (UNIDO) database. We follow Antweiler and Trefler (2002) in constructing proxies for land rents and the price of capital. The latter variable is proxied by the price level of investment in the Penn World Tables measured as the purchasing power parity of investment divided by the exchange rate. We use the GDP generated by livestock per unit of pasture in 1985 to proxy land rents in each country. These estimates were obtained from FAO (1992). After adjustments for missing and outlier data, the constructed database is a cross-section of 42 countries which are listed in Table 1A of the Appendix.

It is important to account for the simultaneity between cattle prices and trade flows at the estimation stage. A few options exist to tackle this challenge. Two-step procedures (e.g. Newey 1987; Lee 1995) offer great flexibility, but are less useful in the current context because non-linearities in the model prevent us from estimating the exact reduced form equation. Hence, any two-step estimator is bound not to be consistent (Wooldridge 2002, 236). Full information maximum likelihood (FIML) estimation is another option,[7] but the presence of complex non-linearities makes it difficult to compute the Jacobian at the estimation stage. Hence, we use a Poisson GMM procedure (Winkelmann 2008, 164) to address the simultaneity issues.

Remoteness variables are commonly used in the gravity literature to proxy for the price indices (e.g. Brun et al. 2005; Carrère 2006). Hence, the benchmark instruments for the price indices (i.e. $\delta_i^f(\cdot)$, $\rho_j^f(\cdot)$, $\delta_j^a(\cdot)$, and $\rho_i^a(\cdot)$) consist of augmented remoteness variables that encompass policy and distance variables. These instruments are specified as: $IV(\delta_i^f) = [\sum_z \omega_z^{\text{PROD}} (t_{iz}^f s_{iz}^f \theta_i^f)^{-\vartheta} \text{dist}_{iz}]^{-1/\vartheta}$ and $IV(\rho_j^f) = [\sum_z \omega_z^{\text{GDP}} (t_{zj}^f s_{zj}^f \theta_j^f)^{-\vartheta} \text{dist}_{zj}]^{-1/\vartheta}$ for the beef trade equation, and as $IV(\delta_j^a) = [\sum_z \omega_z^{\text{GDP}} (t_{zj}^a s_{zj}^a \theta_j^a)^{\vartheta} \text{dist}_{zj}]^{1/\vartheta}$ and $IV(\rho_i^a) = [\sum_z \omega_z^{\text{PROD}} (t_{iz}^a s_{iz}^a \theta_z^a)^{\vartheta} \text{dist}_{iz}]^{1/\vartheta}$ for the cattle trade equation, where ω_z^{PROD} and ω_z^{GDP} represent the weights specified as the production capacity of the source country and the GDP of the destination country, respectively. We use $\vartheta = 3$ as a benchmark value. Cattle prices (p_j^a) are instrumented using 5-year lagged prices. Naturally, the benchmark instruments will be subjected to a sensitivity check where alternative parameter values and lags are used.

Column (i) in Table 2 reports the Poisson GMM estimates of equations (12) and (13). The estimate of the elasticity of substitution (σ) is 3.6 and is highly significant at the 1% level. This implies moderate substitutability in consumption between beef products of different origins. The estimate of the elasticity of transformation (γ) is relatively low at 2.3, but highly significant. The low estimate of γ is consistent with significant supply rigidities at the farm level. In the present case, the lack of harmonization in sanitary, phytosanitary and other technical regulations across importing countries implies that diversification is costly. Furthermore, this parameter can capture other impediments such as quarantine controls. The implied direct effects of distance are -2.8 for cattle (i.e. $-\gamma \times \chi$) and -1.7 for beef (i.e. $-\sigma \times \psi$).[8] The more restrictive distance effects for live cattle relative to beef can be easily explained by the logistic challenges of shipping live animals over long distances.

The estimates of the other parameters have the expected signs and are highly significant. The coefficient on the per-unit cost of cattle production (α) is positive. The estimates of the cost parameters on cattle product and on labor and capital in the production of beef (λ_p, λ_w, and λ_r, respectively) are positive and significant. The value of β is larger than one and is consistent with the second-order conditions associated with profit maximization.

Column (ii) in Table 2 presents the estimation results for a slightly different specification of the empirical model. These results explicitly account for the EU import embargo on hormone-treated cattle/beef. It should be noted that part of the impact of the EU embargo is captured by

Table 2. Poisson GMM estimates of the parameters of the import demand and export supply schedules.

Parameters	Description	Basic specification (i) Estimate (standard error)	EU embargo (ii) Estimate (standard error)
σ	Elasticity of substitution (beef)	3.601 (0.217)	3.578 (0.220)
γ	Elasticity of transformation (cattle)	2.313 (0.281)	2.336 (0.288)
ψ	Distance (beef)	0.463 (0.046)	0.476 (0.047)
χ	Distance (cattle)	1.218 (0.101)	1.207 (0.106)
α	Cost of production (cattle)	0.781 (0.116)	0.769 (0.112)
β	Aggregate output (cattle)	1.657 (0.157)	1.633 (0.161)
λ_p	Price of cattle (beef)	0.417 (0.048)	0.432 (0.052)
λ_w	Price of labor (beef)	0.353 (0.044)	0.330 (0.049)
λ_r	Price of capital (beef)	0.230 (0.051)	0.238 (0.055)
HR^f	Dummy variable hormone-treated beef		−0.265 (0.149)
HR^a	Dummy variable hormone-treated cattle		−0.204 (0.114)
	RESET-1 (p-value)	0.491	
	RESET-2 (p-value)	0.428	

Notes: Robust standard errors are between parentheses. A total of 1,722 observations are available for each specification. Column (i) reports the Poisson GMM estimates of the basic model defined in equations (12) and (13) with the sum of the parameters for the beef cost function (i.e. λ_p, λ_w and λ_r) restricted to one. Column (ii) reports the results when a dummy variable accounting for the EU embargo on imports of hormone-treated cattle/beef is added to the basic specification (i). Ramsey's (1969) RESET test statistics for the parsimonious model are reported where RESET-1 uses the squares, cubes and quadratic powers of the fitted values of the model and RESET-2 uses only the squares of the fitted values of the model.

the CET parameter, which measures frictions in substituting destinations in cattle trade, and through the cattle price in the EU. The import embargo may be seen as an exporting-country targeted policy that requires special attention. Although the embargo does not discriminate across countries *per se* (as it applies to all hormone-treated cattle/beef regardless of origin), it affects countries in which the use of growth hormones is widespread such as the US, Canada, Australia, and New Zealand. Hence, a dummy variable for all inward bilateral trade flows going to the EU and originating from these four countries was added to the equations of cattle (HR^a) and beef (HR^f).[9] The parameters associated with this dummy variable are significant at the 10% level, but the inclusion of this dummy variable did not affect very much the estimates of the parameters considering how similar they are to the estimates in column (i).

We computed Ramsey's (1969) regression specification error test (RESET) for the parsimonious model. The test is performed using a fourth degree polynomial function of the fitted values of the model (RESET-1) as well as strictly using the squares of the fitted values of the model (RESET-2). The test did not reject the null hypothesis that the parsimonious model is correctly specified.[10] Finally, we investigated the sensitivity of the Poisson GMM procedure when assigning different values to the parameter ϑ (ranging from 1 to 10) in the construction of the instruments and using different lags of the cattle prices (ranging from a 1-year lag to a 10-year lag). The empirical results remain quantitatively and qualitatively equivalent to those reported in Table 2.

4. Trade liberalization scenarios

The objective of this section is to assess the effects of two policy liberalization scenarios on trade flows using the estimated parameters reported in column (i) of Table 2. We simulate the following scenarios: (1) full liberalization which entails the elimination of tariffs and domestic and export subsidies; (2) a partial liberalization which could be construed as a hypothetical Doha outcome. It is important to note that the liberalization scenarios strictly address policies targeting beef and cattle production and trade. A truly comprehensive liberalization scheme would involve the elimination of subsidies and trade barriers in the feed grain sectors and thus would likely affect the cost structure of livestock producers which in turn would trigger trade adjustments.

It is unknown at this stage what concessions are likely to emerge at the end of the Doha Round, provided a successful conclusion will ultimately be achieved. The WTO's trade negotiations resumed in March of 2007 and the Chair of the agriculture negotiations released a draft agreement text on 17 July 2007 outlining potential compromise solutions. Our Doha scenario is based on these draft modalities and includes the total removal of export subsidies and a 50% cut in domestic support. Tariffs are lowered depending on whether protection is in the form of a Tariff-Rate Quota (TRQ) or a tariff.[11] WTO members would be allowed to identify between 4% and 6% of their tariff lines as 'sensitive' and thus apply a 'distinct treatment for tariff cuts' as long as it does not prevent 'substantial improvement' in market access (WTO 2007). Hence, the Doha scenario includes tariff cuts of 20% when there are TRQs and 50% in all other instances. It should be emphasized that the estimated supply rigidities hindering cattle trade remain in effect in all four scenarios.[12]

Table 3 reports the impacts of liberalization on exports and imports of cattle for selected countries. Table 4 reports the impacts of liberalization on beef exports and imports for selected countries. The baseline trade volumes of each country are also reported. There is a considerable amount of intra-industry trade in the cattle/beef industry and thus the results of the liberalization scenarios are sorted out according to their impact on imports

Table 3. Impacts of full and Doha liberalization scenarios on cattle exports and imports of selected countries.

	Baseline volume (live weight MT)	Full liberalization scenario		Doha scenario	
		Estimated effect (%)	95% confidence interval	Estimated effect (%)	95% confidence interval
Exporters					
EU	22,205	−42.6	−53.2, −31.3	−30.5	−39.1, −22.7
US	402,169	−66.1	−84.6, −49.3	−45.2	−57.0, −35.1
Australia	125,761	−76.5	−94.1, −58.8	−56.5	−70.1, −43.5
Canada	771,564	10.3	7.9, 12.9	7.1	5.3, 9.2
Mexico	198,615	8.0	6.0, 10.4	5.8	4.3, 7.6
Importers					
EU	28,165	−57.4	−71.2, −42.8	−41.8	−53.9, −31.4
US	823,779	−11.4	−15.2, −8.0	−7.5	−9.9, −5.4
Japan	12,306	−89.2	−109.6, −70.2	−52.5	−64.6, −41.0
Brazil	5,691	60.9	48.1, 75.5	44.0	34.0, 55.2
Canada	305,301	−34.2	−42.7, −25.6	−21.4	−27.0, −16.2
Mexico	115,610	−22.7	−29.0, −17.3	−13.6	−17.4, −9.9

Notes: The estimated effects of the '"full liberalization"' and '"Doha"' scenarios on the export volume of country *j* are defined as: $((\hat{Q}^{a}_{.,j})^{\mathrm{FT}} - (\hat{Q}^{a}_{.,j})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{a}_{.,j})^{\mathrm{SQ}}$ and $((\hat{Q}^{a}_{.,j})^{\mathrm{Doha}} - (\hat{Q}^{a}_{.,j})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{a}_{.,j})^{\mathrm{SQ}}$, respectively, where FT stands for free trade, SQ stands for status quo, and Doha stands for Doha partial liberalization. Similarly, the estimated effects of these scenarios on the import volume of country *i* are defined as: $((\hat{Q}^{a}_{i,.})^{\mathrm{FT}} - (\hat{Q}^{a}_{i,.})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{a}_{i,.})^{\mathrm{SQ}}$ and $((\hat{Q}^{a}_{i,.})^{\mathrm{Doha}} - (\hat{Q}^{a}_{i,.})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{a}_{i,.})^{\mathrm{SQ}}$, respectively. The 95% confidence intervals are computed through the simulation techniques of Krinsky and Robb (1986, 1991).

and exports. The results are presented in terms of changes (in %) relative to the status quo (SQ) in accordance with Anderson and van Wincoop's (2003) comparison of predicted trade flows under full liberalization to those predicted under the SQ.[13] Formally, let $(\hat{Q}^{f}_{i,.})^{\mathrm{FT}}$, $(\hat{Q}^{f}_{i,.})^{\mathrm{Doha}}$ and $(\hat{Q}^{f}_{i,.})^{\mathrm{SQ}}$ measure the predicted value of country *i*'s total beef imports under full liberalization (free trade (FT)), the predicted value of country *i*'s total beef imports under the Doha scenario (Doha), and the predicted value of country *i*'s beef imports under the SQ, respectively. The effects of the 'full liberalization scenario' and the 'Doha scenario' on the import volume of country *i* are estimated as: $((\hat{Q}^{f}_{i,.})^{\mathrm{FT}} - (\hat{Q}^{f}_{i,.})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{f}_{i,.})^{\mathrm{SQ}}$ and $((\hat{Q}^{f}_{i,.})^{\mathrm{Doha}} - (\hat{Q}^{f}_{i,.})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{f}_{i,.})^{\mathrm{SQ}}$, respectively. Similarly, the effects of these scenarios on the export volume of country *j* are estimated as $((\hat{Q}^{f}_{.,j})^{\mathrm{FT}} - (\hat{Q}^{f}_{.,j})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{f}_{.,j})^{\mathrm{SQ}}$ and $((\hat{Q}^{f}_{.,j})^{\mathrm{Doha}} - (\hat{Q}^{f}_{.,j})^{\mathrm{SQ}}) \times 100/(\hat{Q}^{f}_{.,j})^{\mathrm{SQ}}$, respectively. The effects of these scenarios on the import and export volumes of cattle are estimated according to the above procedure.

The current methodology allows for the computation of statistically consistent confidence intervals around the predicted impacts of trade

Table 4. Impacts of full and Doha liberalization scenarios on beef exports and imports of selected countries.

	Baseline volume (MT)	Full liberalization scenario		Doha scenario	
		Estimated effect (%)	95% confidence interval	Estimated effect (%)	95% confidence interval
Exporters					
EU	67,736	38.2	30.0, 47.4	−82.3	−104.6, −65.8
US	1,002,639	150.7	120.6, 182.3	57.8	45.0, 70.2
Argentina	33,485	120.4	93.3, 146.9	55.4	42.3, 68.3
Australia	931,695	99.6	80.2, 119.6	48.2	37.6, 59.3
Brazil	125,564	94.6	73.4, 120.7	43.5	32.8, 54.4
Canada	488,000	53.1	40.4, 67.9	35.5	26.5, 46.4
Importers					
EU	144,073	1438.1	1107.3, 1825.9	224.2	169.8, 289.1
US	1,013,187	−45.6	−59.4, −34.5	−23.3	−29.8, −17.4
Japan	772,549	94.0	72.6, 117.5	54.6	43.1, 67.8
Argentina	13,329	−27.2	−36.6, −21.9	−22.0	−27.6, −16.5
Brazil	27,439	20.1	14.7, 25.6	16.9	12.5, 21.3
Canada	227,543	24.8	18.5, 30.4	14.7	11.0, 18.5
Mexico	503,121	19.0	13.9, 24.2	10.3	7.5, 13.4
South Korea	206,475	35.7	28.0, 44.1	19.0	14.3, 24.2

Notes: The estimated effects of the '"full liberalization"' and '"Doha"' scenarios on the export volume of country j are defined as: $((\hat{Q}^f_{.,j})^{\mathrm{FT}} - (\hat{Q}^f_{.,j})^{\mathrm{SQ}}) \times 100/(\hat{Q}^f_{.,j})^{\mathrm{SQ}}$ and $((\hat{Q}^f_{.,j})^{\mathrm{Doha}} - (\hat{Q}^f_{.,j})^{\mathrm{SQ}}) \times 100/(\hat{Q}^f_{.,j})^{\mathrm{SQ}}$, respectively, where FT stands for free trade, SQ stands for status quo, and Doha stands for Doha partial liberalization. Similarly, the estimated effects of these scenarios on the import volume of country i are defined as: $((\hat{Q}^f_{i,.})^{\mathrm{FT}} - (\hat{Q}^f_{i,.})^{\mathrm{SQ}}) \times 100/(\hat{Q}^f_{i,.})^{\mathrm{SQ}}$ and $((\hat{Q}^f_{i,.})^{\mathrm{Doha}} - (\hat{Q}^f_{i,.})^{\mathrm{SQ}}) \times 100/(\hat{Q}^f_{i,.})^{\mathrm{SQ}}$, respectively. The 95% confidence intervals are computed through the simulation techniques of Krinsky and Robb (1986, 1991).

liberalization scenarios. While the parameters of the model may be asymptotically normally distributed, it is difficult to derive the asymptotic distribution of predicted trade flows. We rely on the simulation techniques of Krinsky and Robb (1986, 1991) to approximate the distribution of the predicted trade patterns.[14] The simulation exercise requires drawing from the joint asymptotic distribution of the parameters' estimates and computing predicted trade flows for a given set of independent variables. The exercise is repeated 1000 times. The simulated values are sorted in ascending order and the 2.5 and 97.5 percentile values are used as bounds of the confidence intervals. The confidence intervals for the full liberalization and Doha predicted changes in the predicted values of trade flows are reported in Tables 3 and 4 between brackets.

The most noticeable feature of the estimates displayed in Tables 3 and 4 is that most of them are small relative to the effects usually reported in the literature (e.g. Anderson and van Wincoop 2003, 2004). In fact, some estimates (mainly in the case of cattle) are negative, thus indicating that either imports or exports under a distorted environment are larger than under full liberalization. An import tariff (or export subsidy) can always be decomposed into an equivalent production subsidy and consumption tax. Tariff removal in the downstream sector can lower implicit production subsidies in some foreign markets and lead to higher beef exports. *Ceteris paribus*, this would increase the domestic demand for cattle and lower cattle exports. A similar argument can be made on the import side when looking at reductions in beef export subsidies implied by the full liberalization exercise. These results highlight the importance of modeling vertical linkages when analyzing trade liberalization for the agri-food sector.

Table 3 indicates that EU cattle *exports* would decrease if tariffs and subsidies were eliminated. More specifically, full liberalization in both the cattle and beef sectors would induce reduction in cattle exports of 43% from the baseline volume of 22,205 live weight MT. Moving to full liberalization from the SQ would decrease cattle exports of the US and Australia by 66% and 76% (the baseline volumes are 402,169 and 125,761 live weight MT, respectively). The confidence intervals around the point estimates of the impacts on exports under both the full liberalization and Doha scenarios span only negative values for the EU, the US, and Australia.

Table 3 also displays the impact of the scenarios on cattle *imports* of selected countries. Full liberalization scenario indicates that EU cattle imports would fall by 57% (with a 95% confidence interval of −71, −43). The baseline volume in that case is 28,165 live weight MT. The full liberalization and the Doha scenarios predict that the US cattle imports would decrease of, respectively, 11% and 7%. The baseline volume of US cattle imports is 823,779 live weight MT. The effects for Japan are negative under both scenarios which mean that its cattle imports would continue falling as all countries move to full liberalization. The results indicate that Brazil would experience import growth following liberalization whereas Canada and Mexico cattle imports would decrease.

The effects of full and partial liberalization plans on beef trade for selected countries are reported in Table 4. The results show that full liberalization would lead to 38% increase in EU beef *exports* from a baseline volume of 67,736 MT. The decrease in EU cattle exports under full liberalization (Table 3) contribute to the increase in EU beef exports. A more detailed investigation revealed that EU beef exports would fall by around 92% if only subsidies were eliminated. In contrast, EU beef exports would increase by around 105% if only tariffs were eliminated. These results are consistent with the widely-held perception that EU subsidies introduce important distortions. They also illustrate the potential ‘retaliatory’ nature of import tariffs imposed by EU's trading partners, i.e. import tariffs tend to lower EU beef exports while EU export subsidies increase them. The predictions show that the Doha scenario would induce a decrease of 82% in EU beef exports. Increases in EU beef *imports* from the baseline volume of 144,073 MT are remarkable, achieving a high of 1438% under the full liberalization scenario. The corresponding figures under the Doha scenario are also considerable at 224%. The EU confidence intervals in Table 4 illustrate the uncertainty associated with the full liberalization and partial liberalization Doha scenarios. Still, it is evident that changes in the EU's highly distorting policies would induce significant domestic adjustments which might explain the EU's reluctance to support ambitious liberalization proposals in agriculture.

The full liberalization and Doha liberalization scenarios positively affect US beef exports (point estimates of, respectively, 151% and 58% from a baseline volume of 1,002,639 MT) and induce reduction in the US beef imports (point estimates of, respectively, 46% and 23% from a baseline volume of 1,013,187 MT). Argentina, Australia, and Brazil beef exports would also experience considerable growth under both scenarios. The full and Doha liberalization scenarios show that Japan's beef imports would increase, respectively, by about 94% and 55% from a baseline volume of 772,549 MT. The results show that Canada would see its current beef exports increase by about 53% and 36% from a baseline volume of 488,000 MT under the full liberalization and Doha scenarios, respectively. Also, the results show that Canada beef imports would increase by 19–30% and by 11–18% under the full liberalization and Doha scenarios, respectively.[15]

Using the predictions in imports and exports under the two liberalization scenarios, we can predict overall trade flow outcomes associated with each liberalization scenario. The overall effects of full liberalization on trade in live cattle would entail a reduction of 405 thousand live weight MT. The full liberalization scenario yields an overall increase in beef trade of 2890 thousand MT. Using the beef equivalent measure of live cattle (considering a conversion rate from cattle to beef of 0.45), there would be an overall net increase in beef equivalent trade of 2708 thousand MT. The Doha scenario would reduce the overall cattle trade by 274 thousand live weight MT. This prediction amounts to a reduction in beef equivalent trade of live cattle of 123 thousand MT. There would be an overall increase in beef trade of 1274 thousand MT. Hence, there would be an overall net increase in beef equivalent trade of 1151 thousand MT. Our simulated trade liberalization outcomes in the cattle and beef sectors suggest that a Doha agreement would exacerbate the general trend toward faster growth in trade in processed products documented by the WTO for a long list of agricultural and food products.[16] Finally, Tables 3 and 4 reveal that our predictions would bring about significant changes in the market shares of exporting countries, thus making ambitious trade liberalization in the Doha Round all the more remote.

5. Conclusion

The current round of multilateral negotiations at the WTO is in a deadlock. While some progress has been made with respect to disciplining general forms of export subsidies in agriculture, there are significant disparities between WTO members' negotiating positions on the two other pillars of agricultural issues, namely market access and trade distorting subsidies. Agri-food markets have distinct features from manufacturing sectors. Vertical linkages between upstream and downstream industries, supply-rigidities arising from non-tariff barriers and product differentiation in processed products must be accounted for when evaluating the impacts of liberalizing agri-food trade.

We developed a gravity framework to explain bilateral trade flows of processed food products *and* primary agricultural commodities. Our theoretical framework accounts for linkages between the export supply functions for the primary product and import demand schedules for the processed product. Supply rigidities in the upstream level of the market are captured by a constant elasticity of transformation that measures the extent by which it is difficult for exporters of the primary product to switch destinations. This particularity allows us to analyze various trade liberalization scenarios in the presence of non-tariff barriers. We apply our framework using cattle and beef trade flows. This sector involves a large degree of intra-industry trade and there exist important variations in the levels and composition of support across countries and products. The gravity model is estimated in its multiplicative form in order to account for zero bilateral trade flow observations that are prevalent in commodity level datasets. The estimation is carried out using a Poisson GMM procedure to account for the endogeneity of prices. The estimates of the parameters of the model are used to simulate the impacts of various trade liberalization scenarios. Confidence intervals around the predicted impacts of trade liberalization are computed using parametric bootstrap methods.

The results confirm the existence of significant product differentiation at the consumers' level with respect to the source of the product. This is consistent with the so-called Armington hypothesis. The low estimate of the elasticity of transformation suggests that there are significant impediments to substituting cattle exports across destinations from an exporting country's perspective. Two trade liberalization scenarios are simulated. The first scenario features the elimination of tariffs and domestic and export subsidies. The second scenario calls for the removal of export subsidies, cutting in half trade-distorting domestic subsidies, and implementing tariff cuts that recognize the sensitive nature of the cattle/beef industry for some countries. Despite the uncertainty surrounding the future of the Doha Round of multilateral talks, the latter scenario is interpreted as a hypothetical Doha compromise.

The US, Argentina, Australia, and Brazil emerge as the beef exporting countries that stand to benefit the most from cuts in tariffs and subsidies under the full liberalization and Doha scenarios. Beef imports in the EU and Japan would significantly increase. However, the US cattle trade balance would worsen under these scenarios since reductions in exports outweigh reductions in imports. Canada's cattle trade balance would improve under the full liberalization and Doha scenarios. Canada would also experience an improvement in its beef trade position as exports would increase at a higher rate than imports under both scenarios. If both the cattle and beef sectors were fully liberalized, we predict that overall cattle trade would decrease by 405 thousand live weight MT whereas overall beef trade would increase by 2890 thousand MT. These outcomes would be accompanied by substantial changes in the market shares of exporting countries.

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Notes

1. The most publicized dispute about a sanitary regulation is perhaps the EU ban on hormone-treated cattle/beef (Bureau, Marette, and Schiavina 1998; Wilson, Otsuki, and Majumdsar 2003). Canada and the US challenged the EU ban on imports of hormone-treated cattle/beef, but the ban remained in effect even when the World Trade Organization's (WTO's) dispute settlement panels ruled that it ought to be lifted. The EU chose to be subject to retaliatory measures by the US and Canada. The role of the embargo on hormone-treated cattle/beef in the empirical model will be discussed below.
2. The 'constant elasticity aggregator' has also been used in empirical studies aiming at measuring technical efficiency in the case of multi-output production function (e.g. Fernandez, Koop, and Steel 2005).
3. Data featuring long panels would have been better suited but were not available.
4. Martin and Pham (2008) argued that the PPML advocated by Santos Silva and Tenreyro (2006) may suffer from a bias when a large number of zeros are present in the data and proposed the threshold Tobit estimation method of Eaton and Tamura (1994). Santos Silva and Tenreyro (2009) responded by showing that the PPML method performs well when the data is generated as a finite mixture of gamma variates, naturally characterized by a large proportion of zeros. Santos Silva and Tenreyro (2009) also argued that the simulation outcomes in Martin and Pham (2008) are defective because the data is not generated by a constant elasticity model.
5. It is important to note that the assumption of monopolistic competition has no qualitative and quantitative implications in the empirical model as the mark-up $\sigma/(\sigma-1)$ is absorbed in the constant term of the regression.
6. The cattle category covers cattle and buffaloes as specified in the Food and Agriculture Organization (FAO) coding system. It includes breeding and

slaughter/feeder cattle. The potential dynamic effects introduced by breeding cattle trade were left aside because of data availability limitations and the small share of breeding cattle in total cattle trade. The beef classification covers meat of cattle; offals of cattle, edible; meat of cattle, boneless; meat of beef dried, salted, smoked; meat of buffaloes; offals of buffaloes, edible; as specified in the FAO coding system.

7. For example, the threshold Tobit estimator of Eaton and Tamura (1994) could be implemented using FIML techniques.
8. It is a common practice in the gravity literature to use the coefficient of the log of distance to make inference about the effect of doubling the distance. This is computed as 2 to the power of the coefficient estimate. From our direct effects, we find that cutting distance in half raises trade in cattle and beef by a multiple of 6.96 and 3.25, respectively. However, these are direct effect estimates that do not account for the complex indirect effects that arise through the multilateral resistance terms and the price equation.
9. This dummy variable captures part of the impacts of the Bovine Spongiform Encephalopathy (BSE) cases in Europe. Given the current sample period, we avoid dealing with potential impacts of BSE cases in North America.
10. We also used the Wald, Lagrange Multiplier (LM) and Rao's F versions of the RESET test. Shukur and Edgerton (2002) showed that Rao's F-test performs particularly well in small samples. All these tests do not reject the null hypothesis that the model is correctly specified.
11. TRQs are two-tier tariffs and act *de facto* as import quotas in many cases as they set a binding level of imports because in-quota imports are taxed at a very low rate while over-quota imports would be taxed at a very high rate.
12. Copeland (1990) showed that reductions in negotiated tariffs can induce the tightening of non-negotiated trade barriers. In our model, this would exacerbate supply rigidities. However, it could be argued that the provisions of the WTO's Agreement on Agriculture have gone a long way to mitigate supply rigidities and to prevent the abuse of technical regulations in response to liberalization. Our assumption can be seen as a compromise between opposite, yet plausible views.
13. In some studies, the border effects are computed in terms of the ease with which goods are exported relative to the ease with which goods are traded domestically (see McCallum 1995; Ch. 5 in Feenstra 2004).
14. Standard bootstrapping methods are not appealing in this instance because the model is highly non-linear.
15. The magnitudes of the effects of the full and Doha liberalization scenarios are undoubtedly affected by existing preferential tariff rates. For instance, the impact of full and Doha liberalization scenarios between preferential trade agreement partners is expected to be lower than when reductions are applied to MFN tariff rates, *ceteris paribus*.
16. For more details, see http://www.wto.org/english/news_e/pres04_e/press378_annex_e.pdf

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Appendix

Table 1A. List of countries.

European Union	Colombia	Indonesia	Philippines
United States	Costa Rica	Israel	South Africa
Japan	Dominican Rep.	Korea Rep.	Sri Lanka
Argentina	Ecuador	Malaysia	Syria
Australia	Egypt	Mexico	Thailand
Bangladesh	Ethiopia	New Zealand	Turkey
Bolivia	El Salvador	Nigeria	Uruguay
Brazil	Ghana	Norway	Venezuela
Cameroon	Guatemala	Pakistan	Zimbabwe
Canada	Honduras	Panama	
Chile	India	Peru	