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# **Environmental Regulation and Implications for Competitiveness in International Pork Trade**

**Mark R. Metcalfe**

Environmental concerns linked to hog production are growing in the United States, Canada, and the European Union. New regulations controlling animal manure management are being imposed to address these concerns. This study determines that potential increases in U.S. and Canadian environmental regulation would have minimal effects on the relative competitiveness of pork exports for these countries. By contrast, more stringent European Union regulations have the potential to significantly reduce EU competitiveness and contribute to the trend of increasing export market share for U.S. and Canadian pork products.

*Key words:* competitiveness, hog production, pork processing, regulation, trade

## **Introduction**

World pork consumption has been increasing over the last decade, and there has been a concurrent increase in the quantity of pork traded internationally. Total world pork trade in the year 2000 was approximately three million metric tons, a 43% increase over 1993 levels. Pork production in the United States has increased 9% in the last 10 years, and since 1995, the United States has been a net exporter of pork to the world. Annual U.S. and Canadian exports for the year 2000 and beyond are estimated to exceed 540,000 metric tons, making these two countries the world's largest pork exporters and clearly establishing them as a competitive threat to traditional European pork exporters [U.S. Department of Agriculture/Foreign Agricultural Service (USDA/FAS) 2000a].

The increases in U.S. and Canadian pork exports are due to recent changes in the structure of these industries in combination with recent sanitary restrictions imposed on pork exports from Taiwan (where foot-and-mouth disease was identified) and the Netherlands (where animals were determined to suffer from classical swine fever), creating opportunities for expansion into foreign markets [USDA/Economic Research Service (ERS); Shaw et al.; Hayes 1997, 1998; USDA/FAS 1998].

The European Union (EU), specifically Denmark and the Netherlands, has traditionally enjoyed a presence in the international pork market, while the competitiveness of U.S. exports, until recently, had been handicapped by problems associated with heterogeneous quality and small-scale production. Despite a history of relatively low U.S. feed and labor costs, U.S. pork export quantities did not comprise a significant share of total world pork trade prior to 1995. The recent structural improvements in the U.S. hog and

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pork industries, however, have facilitated the move to larger operations using production technologies yielding the consistent quality of pork demanded in the export market. Pork processors in the United States now benefit from historically low feed and labor costs as well as new industry structure—allowing U.S. pork to become competitive in the international market (Brewer, Kliebenstein, and Hayenga; Hayes 1998).

The new organization of larger and more concentrated U.S. domestic production has been accompanied by rising environmental concerns, which, in turn, have driven increases in the stringency of the environmental regulation facing animal feeding operations (Metcalf 2000b). This increase in the stringency of environmental regulation is not restricted to the United States; hog producers in Northern Europe and Canada are also being forced to comply with more rigorous domestic environmental regulation (European Commission; Blom; Gardner; Leuck and Haley; the Netherlands Ministry of Agriculture 1999; Srivastava and Bamford; Beghin and Metcalf). In fact, binding constraints on the amount of available agricultural land in the animal production regions of the European Union and the resulting overconcentration of nutrients have forced EU policy makers to propose and implement more stringent regulations than those being considered in the United States and Canada.

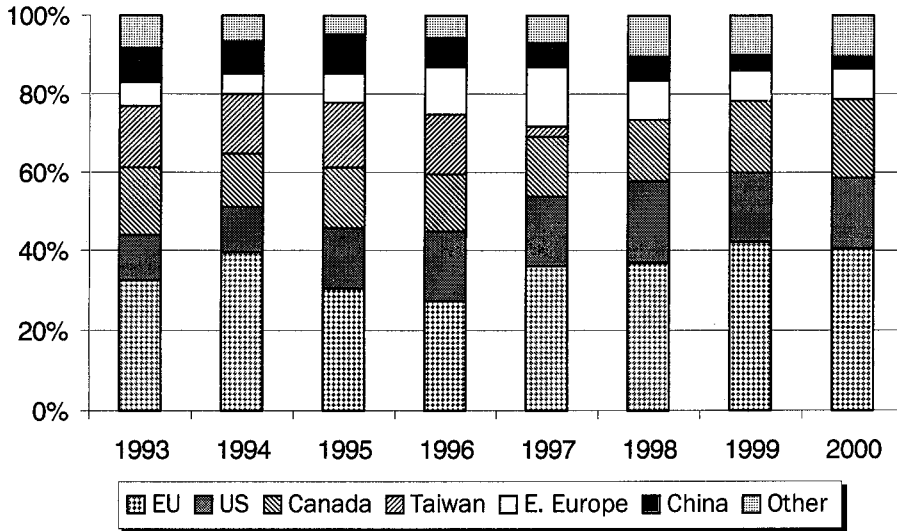
Increases in environmental regulatory stringency lead to higher environmental compliance costs for hog producers. Therefore, the increasingly strict EU regulatory situation may force compliance costs incurred in the European Union to dramatically exceed those in both the United States and Canada, and seriously handicap EU pork competitiveness.

In this analysis, the effects on competitiveness of increasingly stringent environmental regulations imposed on hog production in the United States, Canada, and the European Union are examined. As the United States continues to increase pork exports, what effect does increasing environmental regulation have on pork processing costs, and consequently on competitiveness? The environmental regulations facing the hog industries in the United States, Canada, and the European Union are highlighted, and an equilibrium displacement model is developed to examine the consequences of increasing environmental compliance costs incurred by hog producers.

Increases in regulatory stringency will likely be greater in the European Union than in the United States or Canada. Using this stylized fact, the empirical analysis presented here shows U.S. and Canadian export quantities increase at the expense of decreasing EU exports. European Union export losses are greatest in the important Japanese market, where U.S. and Canadian exports are expected to increase from 1% to 9% depending on the eventual relative differences in compliance costs. This possible loss of EU competitiveness provides an incentive for EU processors to call for harmonization of environmental regulations across countries.

### **Competitiveness and Environmental Regulation**

The concept of competitiveness is an elusive one. There are many definitions of a “competitive” industry based on various measures such as costs, productivity, trade patterns, market share, and profitability. Competitiveness in this study is based on the widely accepted definition proposed by the Canadian Task Force on Competitiveness in the Agri-Food Industry: “Competitiveness is the sustained ability to profitably gain and maintain market share” (Agriculture Canada).



Source: USDA/FAS (2000b).

**Figure 1. World pork exports by country of origin (1993–2000)**

Figure 1 shows the market shares of the major pork-exporting regions for the years 1993 through 2000. The obvious decrease in the competitiveness of Taiwanese exports (due to sanitary restrictions) and the dominance of the European Union, the United States, and Canada in the international pork market can be observed in this graph.

Denmark, France, the Netherlands, Germany, Belgium, and the United Kingdom are the major EU pork-exporting countries, with Denmark alone accounting for 41% of total EU exports in 1999 (USDA/FAS 2000a). Denmark and the Netherlands export the majority of pork outside the EU community. These countries are very competitive in the international pork market because they produce a high-quality product meeting final consumer preferences in several export markets. Danish and Dutch hog producers have also historically benefitted from large government support for exports under the EU Common Agricultural Policy (CAP) (Leuck et al.).

The EU hog and pork industries are highly coordinated in all phases of production and marketing, and benefit from the increased efficiency afforded by this coordination. Even so, producers in the European Union incur higher feed, labor, and facility costs as well as more stringent sanitary restrictions than those faced by producers in the United States and Canada (Brewer, Kliebenstein, and Hayenga). Furthermore, EU producers are facing CAP reforms which purportedly reduce the protection afforded EU producers.<sup>1</sup> All of these factors highlight the potential for increasing environmental regulations to provide opportunities for the U.S. and Canadian pork industries to expand their export market share.

<sup>1</sup> As pointed out by a reviewer, when the EU replaced the variable import levy with a fixed levy under World Trade Organization (WTO) agreements, the result was actually an overall increase in EU protection. This phenomenon occurred because the Agenda 2000 reform drove EU feed costs down to world price levels. Under a variable levy program, reduced feed costs would have resulted in a reduction in tariff levels, but this was not the case under a fixed tariff program. Consequently, as environmental compliance costs have been increasing, EU producers have enjoyed increased protection which has acted to compensate the EU pork industry. As these fixed tariffs are reduced, producers will lose this additional protection and face a greater burden from environmental compliance costs.

**Table 1. Pork Export Quantities (1999, metric tons)**

Importers	Exporters		
	United States	European Union	Canada
Japan	167,458	172,114	53,402
Hong Kong	17,439	99,432	6,500
China	7,746	44,137	*
South Korea	5,069	45,695	2,569
Russia	37,657	307,484	9,434
Eastern Europe	*	169,755	11,286
Canada	32,298	*	—
Mexico	43,824	*	10,611
United States	—	77,800	214,241
Total	557,000	1,002,000	432,000

Source: USDA/FAS (2000b).

Notes: An asterisk (\*) denotes exports are minimal. Totals represent actual total quantities exported by the United States, European Union, and Canada; thus columns do not sum to totals.

Export quantities for those markets important to the United States, Canada, and the European Union are reported in table 1 for 1999. Japan is the largest pork import market in the world. In 1998, the United States, Canada, and the European Union collectively supplied 68% of total Japanese imports, at the expense of banned Taiwanese exports. In 1996, before Taiwanese sanitary trade restrictions were imposed, Taiwan supplied 40% of Japanese imports, and the United States, Canada, and the European Union jointly supplied only 39% of the total (USDA/FAS 1997, 1999a, 2000b).

The analysis performed in this study concentrates exclusively on the changes in competitiveness resulting from changes in environmental compliance costs. Environmental legislation regulating animal feeding operations in the United States varies considerably across individual states, and these regulations have evolved rapidly over the last 10 years. Hog producers in the United States benefit from a low population density and a greater abundance of agricultural land, and therefore do not face the carrying capacity constraints currently experienced by producers in such countries as the Netherlands, Belgium, and Denmark.

Animal feeding operations in the United States are regulated primarily at the state level through restrictions and requirements imposed on manure management systems and field application techniques. The stringency of this regulation varies from state to state, but most states regulate some aspect of manure system construction and manure field application (Metcalf 2000b). Manure management costs in the U.S. are estimated to vary from \$0.40 to \$3.20 per hog,<sup>2</sup> representing 1% to 8% of total hog production costs (Blauser, Forster, and Schnitkey; Zering; Fleming and Babcock; National Pork Producers Council).

The stringency of environmental regulation in Canada is similar to that of the United States (Beghin and Metcalfe). Most Canadian provinces set some type of standards to protect ground and surface water by controlling storage and field application of manure. Canada, like the United States, also benefits from low population density and greater

<sup>2</sup> All dollar values are presented in \$U.S.

land availability in rural areas, attributes likely to lead to lower expected increases in compliance costs when compared to the expected future increases in the European Union (Hacker and Du).

Past studies estimating the magnitude of manure management costs in Canada are unavailable. The manure management costs for Canada are therefore assumed to be similar to those for the United States. This assumption is justified given the similar regulatory and geographical characteristics of the industry, and is supported by Brewer, Kliebenstein, and Hayenga who reported production costs are similar for the United States and Canada.

The 1991 European Community Nitrate Directive, the central legislation regulating European water quality, prescribes minimum water quality standards limiting nitrate from all potential sources. Most hog-producing regions in Northern Europe do not currently satisfy the maximum acceptable nitrate concentrations established in this directive. Implementation of more drastic environmental policies will progressively bring these regions into compliance while simultaneously increasing costs for hog and pork production and limiting the competitiveness of EU exports (Leuck and Haley).

Denmark exports the largest percentage of EU pork and has extensive regulations imposing engineering requirements and setback restrictions as well as nutrient field application standards (Danish Advisory Centre). Environmental regulation also discourages production on large hog operations by linking the size of operation and the required amount of land owned necessary for manure disposal. Based on 1995 values, the Danish Environmental Protection Agency (EPA) estimates the effective environmental compliance cost for manure management is within the range of \$1.20 to \$1.50 per hog on a 1,800-hog operation, while additional compliance costs incurred due to regulation of land ownership are estimated to add approximately \$14 per hog for large operations.<sup>3</sup> The Danish government must continue to implement more stringent policies in order to reduce nitrate emissions by 100,000 tons per year, which represents about half of total agricultural emissions (Fortin and Salaun; Sommer; U.S. Office of Agricultural Affairs-Copenhagen). Therefore, increases in these compliance cost values are expected.

Animal production areas in the Netherlands currently violate 1991 European Community Nitrate Directive standards and, as in Denmark, compliance will require restricting applications of nitrogen on land to rates lower than currently allowed. Dutch operations are regulated by phosphate quotas, regulations on manure treatment, restrictions on storage and field application, and more recently, direct output controls. The compliance costs of phosphate quotas, manure storage regulations, and field application restrictions are estimated at approximately \$4.05 per hog. Necessary future reductions in nitrogen emissions could impose costs on Dutch producers of up to \$27.88 per hog (the Netherlands Ministry of Agriculture 1995; Derrick, Hendriks, and ten Have; Burton; Den Ouden; Vukina and Wossink). Thus it is likely future regulation will compromise the competitiveness of the livestock industries in the Netherlands.

A review of regulation in the United States, Canada, and the European Union demonstrates the relatively stringent and more costly restrictions that will ultimately be imposed on EU producers. A 1999 project by the Agri-Chain Competence Foundation (located in the Netherlands) undertook an in-depth analysis of the pork industries in

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<sup>3</sup> This value is calculated without accounting for the revenue generated through cultivation of the land, and as such is an upper bound on the cost of the land requirement on large hog farms.

Denmark, Canada, the Netherlands, and the United States. This project, known as DECANETHUS, examined the recent technological and institutional changes in the Canadian and U.S. pork industries, and assessed how these factors may have contributed to increased competitiveness of producers and processors in these countries. It is hypothesized in this study that relatively lower environmental compliance costs are a potential additional source of comparative advantage for these North American industries. In the next section, an equilibrium displacement model is developed to determine the magnitude of this potential effect.

## The Model

The equilibrium displacement model developed here is similar to those methods used in past studies and consists of a series of log-linear differential equations which represent supply, demand, and market-clearing relationships in the U.S., Canadian, and EU hog and pork industries (Muth; Sumner and Wohlgenant; Alston; Beghin, Brown, and Zaini). Because the effect of environmental costs on pork processors' costs are presumably small relative to overall pork processing costs, the model is established in log-linear form. The convenience afforded by this approximation is not outweighed by the loss of accuracy.

Variables considered as endogenous to the model are the proportional changes in the prices and quantities of pork processed and the proportional changes in the prices and quantities of the live hogs used as inputs in pork processing.<sup>4</sup> Changes in environmental compliance costs are represented as exogenous "shifts" in the marginal cost curves for live hog producers, and the corresponding effects on the marginal costs of pork processors are then calculated. These changes in pork processing marginal costs are used to obtain changes in prices and to examine changes in the market shares of pork exports. The model specifically considers the competitiveness of exports in the top five U.S. pork export markets listed in table 1.

The model is first developed for U.S. pork processors and hog producers. Domestic demand for U.S. pork is a function of the price of U.S. pork and also of the prices of the Canadian and EU pork imported into the United States.<sup>5</sup> Therefore, the proportional change in U.S. pork demand is represented as:

$$(1) \quad EQ_{us}^{us} = -\eta_{us}^{us} EP_{us}^{us} + \omega_{us}^{eu,us} EP_{us}^{eu} + \omega_{us}^{can,us} EP_{us}^{can}.$$

The operator  $E(x) = dx/x = \ln(x)$  is used to represent proportional changes. For prices ( $P$ ) and quantities ( $Q$ ), superscripts denote the location where the pork is processed, and subscripts denote the location where it is consumed. For example,  $EP_{us}^{eu}$  is the proportional change in price paid by importers in the United States for pork processed and exported from the European Union. The parameter  $\eta_j^i$  is the absolute value of the demand

<sup>4</sup> The value used to represent quantity in the empirical section of this analysis is tons of pork meat, but it should be noted that pork meat is typically sold in various cuts and not as a whole carcass.

<sup>5</sup> It is assumed the prices of other livestock acting as pork substitutes are not significantly affected by changes in hog production costs. Because this model is concerned only with examining those factors which respond to a change in the stringency of environmental regulation faced by hog producers, prices of these substitutes are not included in the domestic demand function.

elasticity for pork produced in  $i$  and consumed in  $j$ . The cross-price elasticities,  $\omega_k^{i,j}$ , capture the substitution that occurs when the price of pork changes. The notation used represents the effect on the quantity of pork exported by region  $j$  which is imported in market  $k$  when there is a change in the price of pork exported from market  $i$ . For example, the value  $\omega_{us}^{eu,can}$  would be the percentage change in the quantity of Canadian pork exported to the United States resulting from a 1% change in the price of EU pork exports.

Foreign demand for U.S. pork exports is a function of U.S. pork export price and the prices of competing Canadian and EU exports. Canada and the European Union are competitors in the pork markets of Japan, Russia, and Hong Kong. The European Union does not export a significant amount of pork to either Canada or Mexico. Hence, only the prices of U.S. and Canadian pork are considered in these markets [Food and Agriculture Organization (FAO) of the United Nations].

The level of U.S. pork export prices is influenced by both transportation costs and trade policy. The transportation costs of moving pork are not insignificant, but for this study it is assumed that changes in environmental regulation do not significantly change transport costs. The displacement model is only affected by changes, so these costs are therefore excluded.

Trade policy is an important factor influencing the price consumers pay for internationally traded pork. The effects of the two-tiered tariff-rate quota (TRQ) policy utilized in Japan and Mexico are examined in this model as a per unit effect incorporated in the prices paid by foreign consumers. Mathematically, this is expressed as:

$$(2) \quad P_i^{*us} = P_i^{us} + t^i, \quad i = 1, \dots, 5,$$

where  $P_i^{*us}$  is the price consumers in market  $i$  pay for pork exported from the United States, and  $t^i$  is the per unit tariff in market  $i$ .<sup>6</sup> Market  $i$  is one of the following import markets: 1 = Japan, 2 = Canada, 3 = Mexico, 4 = Russia, and 5 = Hong Kong. Equation (2) leads to the following relationship representing proportional changes in foreign consumer prices:

$$(3) \quad EP_i^{*us} = \phi_i^{us} EP_i^{us}.$$

The values  $\phi_i^{us}$  represent the ratio of the price received by U.S. processors to the price paid by consumers in market  $i$ , where consumer price is the processor price plus the tariff value. This ratio is calculated for each of the TRQ rates in Japan and Mexico, and the effect of changes in these rates on the model results is then examined.

Given these trade policy effects, proportional changes in the demand for U.S. pork within each foreign market are a function of foreign consumer prices for U.S. pork and the prices of Canadian and EU substitutes. This relationship is written as:

$$(4) \quad EQ_i^{us} = -\eta_i^{us} \phi_i^{us} EP_i^{us} + \omega_i^{eu,us} \phi_i^{eu} EP_i^{eu} + \omega_i^{can,us} \phi_i^{can} EP_i^{can}.$$

Because the total export demand for U.S. pork is equal to the sum of pork exported to all five export markets, the following relationship holds for proportional changes in the total quantity of U.S. pork exported:

<sup>6</sup> Note, the value for  $t$  varies for Japan and Mexico depending on current TRQ tariff rates.



$$(5) \quad EQ_{TE}^{us} = \sum_{i=1}^5 \gamma_i^{us} (-\eta_i^{us} \phi_i^{us} EP_i^{us} + \omega_i^{eu,us} \phi_i^{eu} EP_i^{eu} + \omega_i^{can,us} \phi_i^{can} EP_i^{can}),$$

where  $Q_{TE}^{us}$  is total U.S. exports, and  $\gamma_i^{us}$  is the proportion of U.S. pork exported to market  $i$ .

Equation (5) shows that proportional changes in total U.S. exports are negatively related to the price of U.S. exports. This result is expected because increasing marginal costs for U.S. processors increase the price of U.S. exports, in turn leading to a reduction in the quantity of U.S. exports demanded (a loss of competitiveness). Changes in competitors' pork prices are positively related to U.S. export quantity because increases in EU and Canadian environmental compliance costs lead to increases in EU and Canadian pork prices, and therefore to an increase in the quantity of U.S. exports demanded (a gain in competitiveness).

Total quantity demanded for U.S. processed pork is equal to the sum of the quantities demanded in the domestic market and in all export markets. In terms of proportional changes, this implies:

$$(6) \quad EQ_T^{us} = \beta^{us} EQ_{us}^{us} + (1 - \beta^{us}) EQ_{TE}^{us},$$

where  $\beta^{us}$  is the proportion of U.S. production consumed domestically.

Studies of the meat packing industry suggest processors exert market power which results in a markup of output price over marginal cost (Schroeter and Azzam; Morrison 1997, 2000). Assuming demand elasticities in all markets remain constant for small changes in price, then in terms of proportional changes of prices and marginal costs in the model, it can be proven that

$$(7) \quad EP_j^i = E(MC^i),$$

where  $MC^i$  is the marginal cost of pork processors in market  $i$ .<sup>7</sup> Using this relationship, and inserting equations (1) and (5) into equation (6), provides the following specification representing proportional changes in the quantity of U.S. pork demand as a function of the marginal costs of pork processors in the United States, the European Union, and Canada:

$$(8) \quad EQ_T^{us} = -\kappa_{us}^{us} E(MC^{us}) + \kappa_{us}^{eu} E(MC^{eu}) + \kappa_{us}^{can} E(MC^{can}),$$

where

$$\begin{aligned} \kappa_{us}^{us} &= [\beta^{us} \eta_{us}^{us} + (1 - \beta^{us}) \sum_{i=1}^5 \gamma_i^{us} \eta_i^{us} \phi_i^{us}] > 0, \\ \kappa_{us}^{eu} &= [\beta^{us} \omega_{us}^{eu,us} + (1 - \beta^{us}) \sum_{i=1}^5 \gamma_i^{us} \omega_i^{eu,us} \phi_i^{eu}] > 0, \text{ and} \\ \kappa_{us}^{can} &= [\beta^{us} \omega_{us}^{can,us} + (1 - \beta^{us}) \sum_{i=1}^5 \gamma_i^{us} \omega_i^{can,us} \phi_i^{can}] > 0. \end{aligned}$$

The positive values of the  $\kappa$  parameters are derived from the signs of the parameters contained therein.

<sup>7</sup> The complete derivation of equation (7) may be found in Metcalfe (2000a).

The supply of U.S. pork is based on the marginal cost of U.S. pork processors. Exogenous increases in the environmental compliance costs incurred by U.S. hog producers will lead to increases in the price of hogs in the marginal cost of U.S. pork processing. Proportional changes in the marginal costs of U.S. pork processors are a function of the change in U.S. hog price and U.S. pork quantity, represented as:

$$(9) \quad E(MC^{us}) = \lambda^{us} \alpha_p^{us} EP_h^{us} + \frac{1}{\epsilon_p^{us}} EQ_T^{us},$$

where  $\lambda^{us}$  represents the second partial derivative of the cost function with respect to quantity and hog input price,<sup>8</sup>  $\alpha_p^{us}$  is the proportion of hog price in marginal cost,  $EP_h^{us}$  is the price of hogs in the United States, and  $\epsilon_p^{us}$  is the elasticity of U.S. pork supply.

A representation of the derived demand for hogs is obtained by differentiating the total cost function for pork processors with respect to the hog input price. Proportional changes in the quantity of hogs demanded by U.S. hog producers are assumed to be a function of the price of hogs and the total quantity of pork processed:

$$(10) \quad EQ_h^{us} = -\eta_h^{us} EP_h^{us} + \lambda^{us} \zeta^{us} EQ_T^{us},$$

where  $Q_h^{us}$  is the quantity of U.S. hogs demanded,  $\eta_h^{us}$  is the demand elasticity of U.S. hogs, and the product of  $\lambda^{us}$  and  $\zeta^{us}$  is the scale elasticity of live hog inputs used in U.S. pork processing.

The supply of hogs is derived from the marginal cost of hog production, and this marginal cost is shifted by the amount of environmental compliance costs incurred by hog producers. Changes in the environmental regulations imposed on U.S. hog producers lead to changes in the cost of hog production as producers incur additional manure management costs. These additional costs are referred to as the increase in U.S. environmental compliance costs. Marginal hog cost is obtained from the total cost function, and then proportional changes in marginal cost are calculated with respect to changes in compliance costs such that

$$(11) \quad EP_h^{us} = \alpha_r^{us} ER^{us} + \frac{1}{\epsilon_h^{us}} EQ_h^{us},$$

where  $R^{us}$  is U.S. compliance cost,  $\alpha_r^{us}$  is the proportion of environmental compliance costs in total hog production cost, and  $\epsilon_h^{us}$  is the supply elasticity of hog production.

Assuming equilibrium in the hog market, equating equations (10) and (11), and substituting for  $EP_h^{us}$  in equation (9) provides the proportional change in the total quantity of U.S. pork processed as a function of changes in U.S. pork processing marginal cost and U.S. environmental compliance costs:

$$(12) \quad EQ_T^{us} = \psi^{us} \left[ (\epsilon_h^{us} + \eta_h^{us}) E(MC^{us}) - \epsilon_h^{us} \lambda^{us} \alpha_p^{us} \alpha_r^{us} ER^{us} \right],$$

where  $\psi^{us} = \epsilon_p^{us} / (\epsilon_p^{us} (\lambda^{us})^2 \zeta^{us} \alpha_p^{us} + \epsilon_h^{us} + \eta_h^{us}) > 0$ . Equating pork demand (8) with pork supply (12) closes the U.S. portion of the model and yields the relationship of proportional

<sup>8</sup> Imposing the mathematical condition that the order of differentiation is inconsequential, and using Shephard's lemma, reveals  $\lambda^{us}$  is also equal to the change in hog demand with respect to the change in processed pork quantity. This equality is imposed in equation (10).

changes in the marginal costs of U.S. pork processors with the changes in U.S. environmental compliance costs and changes in EU and Canadian pork processors' marginal costs:

$$(13) \quad E(MC^{us}) = \left[ \frac{N^{us}}{\Omega^{us}} \right] ER^{us} + \left[ \frac{\kappa_{us}^{eu}}{\Omega^{us}} \right] E(MC^{eu}) + \left[ \frac{\kappa_{us}^{can}}{\Omega^{us}} \right] E(MC^{can}),$$

where  $N^{us} = \psi^{us} \epsilon_h^{us} \lambda^{us} \alpha_p^{us} \alpha_r^{us} > 0$ , and  $\Omega^{us} = \psi^{us}(\epsilon_h^{us} + \eta_h^{us}) + \kappa_{us}^{us} > 0$ . As shown by equation (13), increases in the U.S. environmental compliance costs imposed on hog producers lead to increases in the marginal cost of U.S. pork processors. Equation (13) also captures an indirect effect whereby the increasing marginal costs of EU and Canadian pork processors lead to increasing marginal costs for U.S. processors. This indirect effect on U.S. pork processors' marginal costs is due to the resulting increases in U.S. pork output, occurring because less pork is imported.<sup>9</sup>

Analogous relationships for the marginal costs of EU and Canadian pork processors are also calculated in a manner similar to equations (1)–(13) above. To simplify presentation, the derivations of the equations for the EU and Canadian industries have been placed in the appendix. Using the relationships in text equation (13), as well as appendix equations (EU.13) and (CAN.13), provides the following set of three equations directly relating changes in the marginal costs of pork processors to the changes in environmental regulatory costs in the three production regions:

$$(14) \quad \begin{aligned} E(MC^{us}) &= A_1 ER^{us} + A_2 ER^{eu} + A_3 ER^{can}, \\ E(MC^{eu}) &= A_4 ER^{us} + A_5 ER^{eu} + A_6 ER^{can}, \\ E(MC^{can}) &= A_7 ER^{us} + A_8 ER^{eu} + A_9 ER^{can}, \end{aligned}$$

where the values for all  $A_i$  are calculated using the parameters in the model.<sup>10</sup>

The relationships presented in equations (14) are used to calculate changes in marginal costs. These changes in marginal costs are then used in text equation (5) and corresponding appendix equations (EU.5) and (CAN.5) to obtain the changes occurring in total U.S., EU, and Canadian exports, respectively. Export quantities cannot be calculated without the necessary parameter values. These values are discussed in the next section.

### Model Parameters

Most of the necessary parameter estimates are collected from past analyses of the pork and hog industries, while the remaining parameters not found in past studies are calculated in this study. All of the parameter values and sources are provided in table 2, and are discussed below.

Estimates for the percentage of U.S. and EU processed pork consumed domestically ( $\beta^i$ ) are obtained by dividing total domestic consumption of U.S., EU, and Canadian pork by the respective total pork production values. Values for export market shares ( $\gamma^i$ ) are obtained by dividing total quantities of exports to market  $i$  by total U.S. and EU export quantity.

<sup>9</sup> The short-run nature of this model does not allow for expansion of the industry. Therefore, increases in quantity must be produced using existing capacity, which leads to increasing marginal cost.

<sup>10</sup> Presentation of the mathematical expressions of all  $A_i$  variables is tedious and provides little insight. These expressions are available from the author upon request.

**Table 2. Parameter Values and Their Sources**

Parameter	Source(s)	Market		
		United States ( <i>i = us</i> )	European Union ( <i>i = eu</i> )	Canada ( <i>i = can</i> )
$\beta^i$	[b]	0.935	0.941	0.735
$\lambda^i$	[h]	1.390	1.390	1.390
$\xi^i$	[b, h]	0.722	0.756	0.673
$\Phi_{us}^i$	[a]	1.000	1.000	1.000
$\Phi_1^i$	[a]	0.456	0.456	0.456
$\Phi_2^i$	[a]	1.000	—	1.000
$\Phi_3^i$	[a]	0.833	—	0.833
$\Phi_4^i$	[a]	1.000	1.000	1.000
$\Phi_5^i$	[a]	1.000	1.000	1.000
$\varepsilon_h^i$	[g]	0.628	0.628	0.628
$\varepsilon_p^i$	[k]	3.000	3.000	3.000
$\eta_h^i$	[k]	0.750	0.750	0.750
$\alpha_r^i$	[a]	0.045	0.190	0.045
$\alpha_h^i$	[c, j]	0.700	0.622	0.700
$\eta_i^i$	[e, f, i]	1.000	0.770	1.000
$\eta_1^i$	[d]	1.100	1.100	1.100
$\eta_2^i$	[d]	1.250	1.250	1.250
$\eta_3^i$	[d]	6.280	6.280	6.280
$\eta_4^i$	[d]	1.780	1.780	1.780
$\eta_5^i$	[d]	0.460	0.460	0.460
$\eta_{us}^i$	[e, f]	1.000	1.000	1.000
$\gamma_{us}^i$	[b, h]	—	0.118	0.757
$\gamma_1^i$	[b, h]	0.576	0.262	0.196
$\gamma_2^i$	[b, h]	0.148	—	—
$\gamma_3^i$	[b, h]	0.105	—	0.030
$\gamma_4^i$	[b, h]	0.101	0.468	0.003
$\gamma_5^i$	[b, h]	0.068	0.151	0.015

## Sources:

- [a] Calculated in this study
- [b] USDA/FAS (2000b)
- [c] Lawrence, Schroeter, and Hayenga
- [d] Provided through FAPRI, Ames, IA (taken from various past studies for all export markets)
- [e] Skold, Grundmeier, and Johnson
- [f] Moschini and Meilke
- [g] Holt and Johnson
- [h] National Pork Producers Council (NPPC)
- [i] Shaw et al.
- [j] Agri-Chain Competence Foundation, DECANETHUS Project
- [k] Estimated range used

Estimates for the ranges of the effect of TRQ trade policy for Japan ( $\phi_1^i$ ) and Mexico ( $\phi_3^i$ ) are obtained from tariff schedules. These tariffs are applied to U.S. and EU export prices in order to obtain appropriate price shares of U.S. and EU export price to foreign consumer price. The low tariff for Japan is the ad valorem (4.5%) plus specific tax (114%), and the high tariff includes the additional duty imposed using the maximum special safeguard increase of one-third of the low tariff. The low tariff for Mexico is the NAFTA safeguard preferential rate, and the high tariff is the WTO most-favored-nation rate.

The cost shares of environmental compliance in total hog costs ( $\alpha_r^i$ ) have not previously been estimated. These shares are determined here via the existing literature examining the costs of manure management systems. These costs are based on the expected regulatory changes discussed above and a series of waste management cost studies. Blausser, Forster, and Schnitkey calculate U.S. manure management costs incurred for nine different manure management systems used on hog operations. The various systems were constructed for different regulations associated with storage, handling, and land application of manure. Based on their results for 1,000-head operations, manure management costs ranging from \$0.40 to \$3.20 were obtained and are used in this analysis. Cost estimates for large hog feeding operations (i.e., 1,000 head) were chosen because the majority of hogs originate from these larger farms.

A recent study of field application suggests that mixing, loading, unloading, and transportation costs for hog manure are \$0.0113 per gallon for hauling and \$0.0085 per gallon for pumping (Fleming and Babcock). Assuming an average 150-pound finishing hog produces 1.2 gallons of manure per day and is on farm for about 90 days, these costs translate to \$1.22 per hog for hauling and \$0.92 per hog for pumping (Midwest Planning Service). A third cost study, conducted by Zering, calculates total costs per hog of \$1.07 for a lagoon system servicing a 4,800-head hog operation in North Carolina.

The information on U.S. costs from these studies suggests a range of \$0.40 to \$3.20 is appropriate to represent total manure management costs. Given an estimated total hog production cost of \$39.03 for hogs produced on large U.S. operations,  $\alpha_r$  can be calculated as ranging from 0.01 to 0.08 (Brewer, Kliebenstein, and Hayenga). The mean value of  $\alpha_r = 0.045$  is used initially, and sensitivity analysis is then performed over the entire range of values.

Examination of waste management cost literature yielded studies for U.S. and EU producers, but no useful studies on Canadian waste management costs. Therefore, the decision was made to utilize the same cost shares for U.S. and Canadian producers. This assumption is supported in part by the study of Brewer, Kliebenstein, and Hayenga, who examine production costs for U.S., Canadian, and EU producers and note some similarities in these costs between U.S. and Canadian producers. Also, a review of animal waste management regulations between the U.S. and Canada reveals similar regulatory policies and stringency existing between the two countries (Beghin and Metcalfe; Metcalfe 2000b).

Information on EU manure management costs is used to calculate the cost share of environmental compliance in EU hog production. Cost of manure systems and manure transport in Belgium have been estimated to range between \$1.92 and \$5.27 per hog. Future regulation could push these costs to approximately \$17.75 per hog (Rude and Frederiksen; van Hofreither; van Huylenbroeck; Martens).

Environmental compliance costs on large hog farms in Denmark are partially subsidized by the national government, and the cost incurred by farmers for manure

management and land ownership is approximately \$15.50 per hog (Fortin and Salaun; Sommer; U.S. Office of Agricultural Affairs-Copenhagen). Hog producers in the Netherlands face compliance costs of approximately \$4 per hog. However, future control of nitrate emission could increase these costs to an estimated \$27.88 per hog (the Netherlands Ministry of Agriculture 1995; Derrick, Hendriks, and ten Have; Burton; Den Ouden; Vukina and Wossink).

Total EU hog production costs average approximately \$75 per hog, yielding a calculated share of environmental compliance cost to total hog production cost of between 0.027 and 0.37 under current and expected future regulation (Brewer, Kliebenstein, and Hayenga). The mean value of  $\alpha_r^{eu} = 0.19$  is used as a baseline, and then sensitivity analysis over the entire range of values is conducted.

Past studies on the U.S. domestic pork market have calculated domestic demand elasticity ( $\eta_{us}^{us}$ ) ranging from -0.75 to -1.25 (Skold, Grundmeier, and Johnson; Moschini and Meilke). This range is incorporated into the sensitivity analysis. An estimate of -0.77 for EU domestic pork demand ( $\eta_{eu}^{eu}$ ) is taken from an earlier study on the EU meat sector (Shaw et al.). Export market demand elasticities (i.e., excess demand elasticities) are obtained from past studies for all export markets [using data provided through the Food and Agricultural Policy Research Institute (FAPRI), Ames, Iowa]. Note that these elasticity estimates measure short-term changes which would occur during and immediately after regulatory changes. Structural changes in the industry are expected to occur and affect competitiveness in the long term.

U.S., Canadian, and EU pork are assumed to be substitutes in the markets in which they are available. Changes in the price of pork from one country cause changes in the quantities of pork demanded from the other countries. Values representing these cross-price demand elasticities for pork exports ( $\omega_k^{ij}$ ) are not available from previous studies, and are therefore calculated here by assuming consumers minimize expenditures on all pork subject to a constant elasticity of substitution (CES) relationship describing the substitutability of U.S., Canadian, and EU pork. Functional forms for the elasticities are obtained from this optimization; market price and quantity values are used to calculate the elasticity values (Metcalfe 2000a).

Exogenous changes in this model occur because of increases in the environmental compliance costs facing U.S., EU, and Canadian hog producers. As discussed above, manure management costs may rise up to 200% of current environmental costs in the United States and Canada, and as much as 500% in the more stringently regulated European Union (Blauter, Forster, and Schnitkey; Wossink; van Hofreither; Zering; Lauwers; Martens; Fleming and Babcock). Accordingly, to reflect these likely increases, results are presented with U.S. and Canadian compliance costs increasing under scenarios of 0%, 100%, and 200%, while scenarios of 100%, 300%, and 500% are used for the European Union.

## Simulation Results

Simulated changes in U.S., EU, and Canadian export quantities are provided in tables 3, 4, and 5. Results are reported in ranges representing low and high changes in export quantity given a change in domestic regulatory compliance costs. For example, in table 3, a 0% change in U.S. costs leads to a low increase of 2.3% in total exports if Canadian and EU cost increases are also low, and to a high increase of 12.5% in U.S. exports if

**Table 3. Simulated Percentage Changes in U.S. Export Quantities**

Exported to	CHANGE IN U.S. COMPLIANCE COSTS					
	0%		100%		200%	
	Low	High	Low	High	Low	High
Japan	1.7	8.7	1.2	8.2	0.8	7.8
Canada	0.1	4.8	-0.2	4.5	-0.6	4.1
Mexico	-0.6	-3.2	-5.7	-8.3	-10.8	-13.4
Russia	8.8	43.8	7.1	42.1	5.3	40.4
Hong Kong	7.8	39.2	7.4	38.8	7.0	38.4
Total	2.3	12.5	1.3	11.4	0.2	10.4

**Table 4. Simulated Percentage Changes in EU Export Quantities**

Exported to	CHANGE IN EU COMPLIANCE COSTS					
	100%		300%		500%	
	Low	High	Low	High	Low	High
Japan	-0.6	-2.0	-4.7	-6.1	-8.7	-10.1
Russia	-7.2	-7.4	-22.1	-22.3	-36.9	-37.2
Hong Kong	-0.9	-1.8	-4.7	-5.6	-8.5	-9.4
United States	0.9	-3.9	-9.7	-11.7	-14.7	-19.5
Total	-3.5	-4.7	-13.1	-14.3	-22.6	-23.8

**Table 5. Simulated Percentage Changes in Canadian Export Quantities**

Exported to	CHANGE IN CANADIAN COMPLIANCE COSTS					
	0%		100%		200%	
	Low	High	Low	High	Low	High
Japan	1.7	9.6	1.3	9.1	0.8	8.7
Mexico	-0.3	-1.6	-5.5	-6.8	-10.7	-12.1
Russia	8.8	43.6	7.0	41.8	5.2	40.0
Hong Kong	7.9	39.7	7.4	39.2	6.9	38.8
United States	0.2	5.0	-0.6	4.1	-1.5	3.3
Total	0.6	6.4	-0.2	5.4	-1.1	4.5

Canadian and EU cost increases are high. In short, total U.S. exports could increase from 2.3% to 12.5% if current U.S. environmental compliance costs do not increase. Corresponding increases in U.S. exports to the Japanese market are 1.7% and 8.7%. Note these estimates are short term, reflecting changes occurring immediately as regulations change and for the few years following. In the long term, changes in industry structure and geographical location of production can be expected (Metcalf 2001).

Exports from the United States increase in all of the scenarios examined. This increase in U.S. exports comes at the expense of decreasing EU exports resulting from the

large expected increases in compliance costs which could occur in EU hog production. Canadian pork exports increase in most scenarios except those where Canadian compliance costs increase more than U.S. costs. The magnitudes of these changes are significant when increases in compliance costs are asymmetric across countries—that is, when one production region experiences relatively greater increases in compliance costs, there is a corresponding significant decrease in that region's export quantity (i.e., competitiveness).

Given the short-run aspect of the model, it should be noted there are no EU pork exports to Canada and Mexico. Hence, there is no competition for U.S. exports in these markets. Consequently, even as U.S. pork prices increase, there is little loss in U.S. export quantities to these markets. In the long run, if U.S. prices increase, entry of EU pork exports into these markets would diminish U.S. exports.

Gains in total U.S. export quantities range from 0.2% when U.S. compliance cost increases are high relative to EU and Canadian increases, to a gain of 12.5% when U.S. increases are low compared to those in the European Union and Canada. The largest absolute gains are in the important Japanese market where U.S. exports climb from 0.8% to 7.8%. The largest percentage increases occur in the Russian and Hong Kong markets, with increases of approximately 40% when EU compliance costs are high relative to those in the United States.

Losses in total EU exports range from about 3.5% to 23.8%. Large losses for EU exports are expected because compliance cost increases in the European Union will be much greater than those in the United States and Canada. The largest percentage losses for EU exports occur in Russia, the United States, and Japan. Increases in total Canadian pork export quantities are more modest than the gains experienced by the United States, reaching a maximum of 6.4% when Canadian compliance cost increases are relatively low. The largest Canadian increases occur in the markets of Russia, Hong Kong, and Japan.

Sensitivity analysis is performed on the model to examine the effect of the following parameters which past studies<sup>11</sup> have suggested can take multiple values: the price elasticity of U.S. pork demand ( $\eta_{us}^i$ ); price elasticity of the derived demand for hogs ( $\eta_h^i$ ); the elasticity of marginal cost with respect to pork quantity ( $\epsilon_p^i$ ); trade policy effects in the Japanese and Mexican markets ( $\phi_1^i, \phi_3^i$ ); and the cost share of U.S. environmental compliance costs ( $\alpha_r^i$ ).

The sensitivity of the model to each of these parameters was examined separately. Specifically, parameters were changed one at a time in the baseline model, and the resulting changes in export quantities were recorded for all potential changes in regulatory costs. The ranges examined are: 0.75 to 1.25 for  $\eta_{us}^i$ ; 0.5 to 1.0 for  $\eta_h^i$ ; 1 to 5 for  $\epsilon_p^i$ ; 1% to 8% for U.S. and Canadian compliance costs ( $\alpha_r^{us}$  and  $\alpha_r^{can}$ ); 2.7% to 17% for EU compliance costs ( $\alpha_r^{eu}$ ); and the values 0.443 and 0.667 for Japan and Mexico, respectively ( $\phi_1^i$  and  $\phi_3^i$ ), when TRQ levels are surpassed. Using these ranges, the sensitivity analysis provides the degree to which total export quantities change as each of these parameters is varied. Table 6 presents the sensitivity analysis results for each exporting country and each parameter.

The parameter with the greatest influence on the simulation results is the cost share of compliance costs,  $\alpha_r^i$ . The resulting calculations for total export quantity changes

<sup>11</sup> For a complete listing of these studies and their parameters, the interested reader is referred to Metcalfe (2000a).



**Table 6. Sensitivity Analysis Results for Each Parameter by Exporting Country**

Parameter	% Difference in Export Quantity		
	U.S.	EU	Canada
Own-price elasticity of U.S. pork demand ( $\eta_{us}^i$ )	0.13	0.46	0.50
Elasticity of marginal cost w/respect to pork quantity ( $\epsilon_p^i$ )	0.41	0.88	0.15
Own-price elasticity of derived demand for hogs ( $\eta_h^i$ )	0.93	1.01	0.38
Cost share of environmental compliance cost ( $\alpha_r^i$ )	2.26	3.12	2.10
Trade policy effects in Japan and Mexico ( $\phi_1^i, \phi_3^i$ )	0.03	0.04	0.01

differed by 2.26% for the United States, 3.12% for the European Union, and 2.10% for Canada. Changes resulting from TRQ rates in Japan and Mexico ( $\phi_1^i$  and  $\phi_3^i$ ) have the smallest effect on the total exports. Overall, the changes in total export quantities calculated in the sensitivity analysis are relatively stable given the potential variance in these parameters. This sensitivity analysis illustrates the importance of accurately calculating environmental compliance costs because the variance in this parameter has the greatest potential effect on export performance.

## Conclusion

Environmental regulations controlling the manure management aspects of hog production are becoming more stringent in the United States, Canada, and the European Union. This more rigorous regulatory stringency leads to increases in the compliance costs incurred by hog producers, which are then passed on to the pork processing sector. The observed increases in U.S. and Canadian pork export quantities over the last five years are directly attributable to the progressively competitive stance being taken by these industries in world markets. The results of this study suggest that relatively lower compliance costs could provide an additional source of competitiveness for these industries.

Export quantities of U.S. pork totaled 530,000 metric tons in 1999, representing an increase of 364% since 1990. Over this same time period, U.S. export value exceeded \$1 billion, a 214% nominal increase. Exports to the Japanese market, in particular, quadrupled in volume as free trade agreements continued to open this and other markets to U.S. pork exports. Given these increases, exports now account for over 6% of total U.S. pork production and clearly are important to the economic health of the industry (USDA/FAS 1999b).

Although environmental regulation is expected to increase in the United States, this does not significantly affect the competitiveness of U.S. exports. The relatively more stringent regulations that may be imposed in the European Union actually help to increase the short-term competitiveness of U.S. pork producers. Canadian exports also experience an increase given relatively more stringent European Union regulations. In the long run, it is expected there will be changes in industry structure and geographical location of production, which are not modeled in this study.

The most dramatic effects resulting from increasing regulation occur for EU pork processors who experience large decreases in export quantities. This finding suggests

there are benefits available to EU producers and processors from a move toward multi-lateral harmonization of animal manure management regulation in order to minimize the differences in compliance costs across countries.

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## Appendix:

### Derivations of Equations for European Union and Canadian Pork and Hog Markets

The numerical values of the equations presented in the appendix for the EU and Canadian markets correspond to the numerical equations presented in the text for the U.S. market. For example, equations (EU.1) and (CAN.1) are the EU and Canadian domestic demand, respectively, and correspond to U.S. domestic demand presented in text equation (1).

#### Equation Derivations for EU Pork and Hog Markets

*EU Domestic Demand:*

$$(EU.1) \quad EQ_{eu}^{eu} = -\eta_{eu}^{eu} EP_{eu}^{eu}$$

*EU Export Prices:*

$$(EU.3) \quad EP_i^{*eu} = \phi_i^{eu} EP_i^{eu}$$

EU Total Export Demand:

$$(EU.5) \quad EQ_{TE}^{eu} = - \left[ \gamma_{us}^{eu} \eta_{us}^{eu} \Phi_{us}^{eu} + \sum_{i=1}^5 \gamma_i^{eu} \eta_i^{eu} \phi_i^{eu} \right] EP_i^{eu} \\ + \left[ \gamma_{us}^{eu} \omega_{us}^{us,eu} \Phi_{us}^{us} + \sum_{i=1}^5 \gamma_i^{eu} \omega_i^{us,eu} \phi_i^{us} \right] EP_i^{us} \\ + \left[ \gamma_{us}^{eu} \omega_{us}^{can,eu} \Phi_{us}^{can} + \sum_{i=1}^5 \gamma_i^{eu} \omega_i^{can,eu} \phi_i^{can} \right] EP_i^{can}$$

EU Total Demand:

$$(EU.6) \quad EQ_T^{eu} = \beta^{eu} EQ_{eu}^{eu} + (1 - \beta^{eu}) EQ_{TE}^{eu}$$

EU Total Demand as a Function of Marginal Costs:

$$(EU.8) \quad EQ_T^{eu} = -\kappa_{eu}^{eu} E(MC^{eu}) + \kappa_{eu}^{us} E(MC^{us}) + \kappa_{eu}^{can} E(MC^{can}),$$

where

$$\kappa_{eu}^{eu} = \beta^{eu} \eta_{eu}^{eu} + (1 - \beta^{eu}) \left[ \gamma_{us}^{eu} \eta_{us}^{eu} \Phi_{us}^{eu} + \sum_{i=1}^5 \gamma_i^{eu} \eta_i^{eu} \phi_i^{eu} \right] > 0 \\ \kappa_{eu}^{us} = (1 - \beta^{eu}) \left[ \gamma_{us}^{eu} \omega_{us}^{us,eu} \Phi_{us}^{us} + \sum_{i=1}^5 \gamma_i^{eu} \omega_i^{us,eu} \phi_i^{us} \right] > 0 \\ \kappa_{eu}^{can} = (1 - \beta^{eu}) \left[ \gamma_{us}^{eu} \omega_{us}^{can,eu} \Phi_{us}^{can} + \sum_{i=1}^5 \gamma_i^{eu} \omega_i^{can,eu} \phi_i^{can} \right] > 0$$

EU Pork Supply:

$$(EU.9) \quad E(MC^{eu}) = \lambda^{eu} \alpha_p^{eu} EP_h^{eu} + \frac{1}{\varepsilon_p^{eu}} EQ_T^{eu}$$

EU Hog Demand:

$$(EU.10) \quad EQ_h^{eu} = -\eta_h^{eu} EP_h^{eu} + \lambda^{eu} \zeta^{eu} EQ_T^{eu}$$

EU Hog Supply:

$$(EU.11) \quad EP_h^{eu} = \alpha_r^{eu} ER^{eu} + \frac{1}{\varepsilon_h^{eu}} EQ_h^{eu}$$

EU Hog Market Equilibrium:

$$(EU.12) \quad EQ_T^{eu} = \psi^{eu} \left[ (\varepsilon_h^{eu} + \eta_h^{eu}) E(MC^{eu}) - \varepsilon_h^{eu} \lambda^{eu} \alpha_p^{eu} \alpha_r^{eu} ER^{eu} \right],$$

where

$$\psi^{eu} = \varepsilon_p^{eu} / (\varepsilon_p^{eu} (\lambda^{eu})^2 \zeta^{eu} \alpha_p^{eu} + \varepsilon_h^{eu} + \eta_h^{eu}) > 0$$

EU Pork Market Equilibrium:

$$(EU.13) \quad E(MC^{eu}) = \left[ \frac{N^{eu}}{\Omega^{eu}} \right] ER^{eu} + \left[ \frac{\kappa_{eu}^{us}}{\Omega^{eu}} \right] E(MC^{us}) + \left[ \frac{\kappa_{eu}^{can}}{\Omega^{eu}} \right] E(MC^{can}),$$

where

$$N^{eu} = \psi^{eu} \varepsilon_h^{eu} \lambda^{eu} \alpha_p^{eu} \alpha_r^{eu} > 0$$

$$\Omega^{eu} = \psi^{eu} (\varepsilon_h^{eu} + \eta_h^{eu}) + \kappa_{eu}^{eu} > 0$$

**Equation Derivations for Canadian Pork and Hog Markets***Canadian Domestic Demand:*

$$(CAN.1) \quad EQ_{can}^{can} = -\eta_{can}^{can} EP_{can}^{can} + \omega_{can}^{us,can} EP_{can}^{us}$$

*Canadian Export Prices:*

$$(CAN.3) \quad EP_i^{can} = \phi_i^{can} EP_i^{can}$$

*Canadian Total Export Demand:*

$$(CAN.5) \quad EQ_{TE}^{can} = - \left[ \gamma_{us}^{can} \eta_{us}^{can} \phi_{us}^{can} + \sum_{i=1}^5 \gamma_i^{can} \eta_i^{can} \phi_i^{can} \right] EP_i^{can} \\ + \left[ \gamma_{us}^{can} \omega_{us}^{eu,can} \phi_{us}^{eu} + \sum_{i=1}^5 \gamma_i^{can} \omega_i^{eu,can} \phi_i^{eu} \right] EP_i^{eu} \\ + \left[ \gamma_{us}^{can} \omega_{us}^{us,can} \phi_{us}^{us} + \sum_{i=1}^5 \gamma_i^{can} \omega_i^{us,can} \phi_i^{us} \right] EP_i^{us}$$

*Canadian Total Demand:*

$$(CAN.6) \quad EQ_T^{can} = \beta^{can} EQ_{can}^{can} + (1 - \beta^{can}) EQ_{TE}^{can}$$

*Canadian Total Demand as a Function of Marginal Costs:*

$$(CAN.8) \quad EQ_T^{can} = -\kappa_{can}^{can} E(MC^{can}) + \kappa_{can}^{us} E(MC^{us}) + \kappa_{can}^{eu} E(MC^{eu}),$$

where

$$\kappa_{can}^{can} = \beta^{can} \eta_{can}^{can} + (1 - \beta^{can}) \left[ \gamma_{us}^{can} \eta_{us}^{can} \phi_{us}^{can} + \sum_{i=1}^5 \gamma_i^{can} \eta_i^{can} \phi_i^{can} \right] > 0 \\ \kappa_{can}^{eu} = (1 - \beta^{can}) \left[ \gamma_{us}^{can} \omega_{us}^{eu,can} \phi_{us}^{eu} + \sum_{i=1}^5 \gamma_i^{can} \omega_i^{eu,can} \phi_i^{eu} \right] > 0 \\ \kappa_{can}^{us} = \beta^{can} \omega_{us}^{us,can} + (1 - \beta^{can}) \left[ \gamma_{us}^{can} \omega_{us}^{us,can} \phi_{us}^{us} + \sum_{i=1}^5 \gamma_i^{can} \omega_i^{us,can} \phi_i^{us} \right] > 0$$

*Canadian Pork Supply:*

$$(CAN.9) \quad E(MC^{can}) = \lambda^{can} \alpha_p^{can} EP_h^{can} + \frac{1}{\varepsilon_p^{can}} EQ_T^{can}$$

*Canadian Hog Demand:*

$$(CAN.10) \quad EQ_h^{can} = -\eta_h^{can} EP_h^{can} + \lambda^{can} \zeta^{can} EQ_T^{can}$$

*Canadian Hog Supply:*

$$(CAN.11) \quad EP_h^{can} = \alpha_R^{can} ER^{can} + \frac{1}{\varepsilon_h^{can}} EQ_h^{can}$$

*Canadian Hog Market Equilibrium:*

$$(CAN.12) \quad EQ_T^{can} = \psi^{can} \left[ (\varepsilon_h^{can} + \eta_h^{can}) E(MC^{can}) - \varepsilon_h^{can} \lambda^{can} \alpha_p^{can} \alpha_r^{can} ER^{can} \right],$$

where

$$\psi^{can} = \varepsilon_p^{can} / \left( \varepsilon_p^{can} (\lambda^{can})^2 \zeta^{can} \alpha_p^{can} + \varepsilon_h^{can} + \eta_h^{can} \right) > 0$$

Canadian Pork Market Equilibrium:

$$(CAN.13) \quad E(MC^{can}) = \left[ \frac{N^{can}}{\Omega^{can}} \right] ER^{can} + \left[ \frac{\kappa_{can}^{eu}}{\Omega^{can}} \right] E(MC^{eu}) + \left[ \frac{\kappa_{can}^{us}}{\Omega^{can}} \right] E(MC^{us}),$$

where

$$N^{can} = \psi^{can} \epsilon_h^{can} \lambda^{can} \alpha_p^{can} \alpha_r^{can} > 0$$

$$\Omega^{can} = \psi^{can} (\epsilon_h^{can} + \eta_h^{can}) + \kappa_{eu}^{eu} > 0$$